



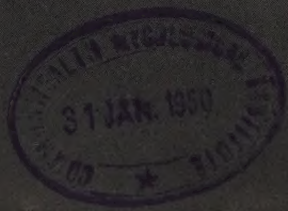
The

HAWAIIAN PLANTERS' RECORD

Vol. LIII

1949

No. 2



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A publication devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among plantations of the Hawaiian Sugar Planters' Association.

L. D. Baver, Editor

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Cover Picture—Forecasting the amount of water to be expected in irrigation ditches, such as the one shown here, is a major part of the forecasting program of the Department of Meteorology. Pictured is a diversion structure and tunnel outlet near the Hana Road, East Maui. The low flows of the stream entering at the right are added to water already collected and pouring out of the tunnel mouth in the background. The augmented flow enters the next section of the tunnel to the left of the picture and is taken through the mountain to be added to again at the next stream bed. This water is carried to the cane fields and used for irrigation. *For more details see article page 47.*

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The Annual Rainfall of East Maui¹

By Luna B. Leopold²

ABSTRACT

East Maui Irrigation Company, serving the sugar plantations on the Maui isthmus, must pay for water derived from lands not under the company's jurisdiction. This payment, which is a substantial sum, is based in part on a map of mean annual rainfall of the East Maui area.

It was mutually agreed by the Territory of Hawaii, represented by the U. S. Geological Survey, and the irrigation company that a revised rainfall map should be constructed by a disinterested third party, and that adjustments of payments would be determined by the new map. The author was asked to prepare the map which accompanies the present paper.

The map of average annual rainfall includes the whole north slope of Haleakala, the 10,000-foot mountain of East Maui. The height of the mountain is sufficient to divert the trade wind flow laterally around it rather than allowing the air to flow over the top as is the case of West Maui. Yet sufficient vertical lifting occurs to provide an annual rainfall of over 400 inches at the wettest place.

The map utilized the records of 116 rain gages, an average of one gage per four square miles. Each gage record was adjusted to a long-term base record to eliminate the effects of differing periods of record at different gages. The annual rainfall at the wettest place near Wailua Iki was determined by this study to be considerably greater than that shown on previously published maps of the area.

Ordinarily when one rain gage experiences a wet year, so also do others in the vicinity. Thus the ratio between gages remains constant from year to year. In the area studied there were found long-period swings in these interstation ratios. Gages in the higher elevation and westward portion (Opana-Olinda area) decreased in rainfall relative to a stable base during the period 1923-1933 and increased relatively in the period 1933-1948. Hana and Waiakamoi, representing the low elevation northern and eastern sectors acted in an opposite fashion, increasing or remaining constant relative to the base during 1923-33. In the later period, 1933-1948, these stations decreased in rainfall relative to the stable base.

This long-term swing in interstation relations is interpreted as an indication that during the period 1923-1933 the stable layer of air at the temperature inversion,

¹ Also published with the approval of the Director as Technical Paper No. 189 of the Pineapple Research Institute of Hawaii.

² Luna B. Leopold is former head, Department of Meteorology, Hawaiian Sugar Planters' Association and Pineapple Research Institute, cooperating.

which marks the top of the clouds (about 7000 feet mean sea level in Hawaii), decreased in height. This decreased the height of cloud tops and caused relative decreases in the rainfall at stations in the 3000-4000 foot elevation zone. At the same time it is conjectured that this phenomenon caused the rainfall at Hana to increase relative to a stable base.

Such long-period changes in the height of the stable inversion layer probably reflect changes in position and strength of the Pacific high pressure cell northeast of Hawaii. Complete upper air temperature data are available for Hawaii only since 1946. Any climatological information on the action of the temperature inversion in years previous to 1946 is of importance in studying the relation of the changes observed in the high pressure cell to local variations in Hawaiian rainfall.

The wettest portions of the Hawaiian Islands rank high in the list of heavy rainfall areas of the earth. These localities of excessive precipitation occur in Hawaii on the windward slopes of the larger volcanic cones or at the summits of the lesser mountains. Their vegetation is truly a jungle forest, the dominant plants being ohia lehua (*Metrosideros collina*), tree fern (*Cibotium chamissoi*), and an exotic fern (*Gleichenia linearis*) which has taken over large portions of the forest floor wherever the upper story allows moderate sunlight to penetrate to the ground.

A nearly unbroken forest canopy, the locally rough surface of lava flows, and the high rainfall prohibit the use of such areas for any purpose except that of water catchments.

The belt of maximum rainfall on East Maui is at 3000 feet, decreasing toward both higher and lower elevations. At approximately 7000 feet the forest ends at a sharp boundary and is replaced at higher elevations by a xerophytic zone of shrubs and grass (4).

The development and maintenance of pipelines, tunnels, and ditches to collect and distribute water for the irrigation of the drier areas has provided both the stimulus and opportunity to maintain a network of rain gages probably unequaled in localities of comparable rainfall.

Isohyetal maps of the Hawaiian Islands have been published by the Territorial Planning Board (8), by Voorhees for Oahu (9), by Halstead and Leopold for Oahu (1), Stearns and MacDonald for Maui (7), and by others. However, all the available maps either used incomplete records or the station rainfall values were not adjusted to a long period base record.

Opportunity to make a detailed study of annual rainfall on East Maui was provided through the desire of East Maui Irrigation Company to obtain a revised isohyetal map of their water catchment area. This company pays for irrigation water derived from land not under its jurisdiction and the payments are based on a mean annual rainfall map.

THE RAINFALL RECORDS

The longest rainfall records of East Maui are for stations located along the main coastal road connecting Hana with the central isthmus. There are numerous gages in the sugar, pineapple, and ranch lands on the isthmus and the west slopes

of Haleakala cone. In the rain forest of the windward slopes, the gages have been maintained only with great effort because the interior is accessible only by horse or, in many places, by foot. The few trails have been cut for inspection of

water supply structures and for the collection of rainfall and streamflow records.

These gages which are difficult to reach are read once each month or intermittently. Because of the great rainfalls, standard gages cannot be used. The gages are approximately the same over-all size as a standard gage but with the collection ring reduced to provide a ratio of ring to storage can area of 1:2 or 1:10. Accessible gages are read daily or after each rain.

In the rough forested areas of Hawaii, it is impossible to find locations for rain gages the exposure of which fulfills the requirements usually met in mainland United States. The rain gage shown in Figure 1 is a typical mountain gage, placed in a small natural clearing in a thickly forested area.

The measurements of rain at such gages are necessarily rough. In the case of gages having a 1:10 ratio, depth of water collected cannot be read closer than the nearest whole inch of rain. This means, however, that the ratio of error to total catch is comparable to standard gage readings in areas of lower rainfall. The readings themselves are subject to a multitude of errors. Since the depth read must be multiplied by the ratio of catchment to gage area, there is sometimes a possibility that the proper multiplication was not made.

Figure 1. Rain gage No. 342, Puohakamoa No. 2, on East Maui. Gage is located in a clearing in the rain-forest where annual rainfall is 250 inches. Trees in background are ohia lehua. The diameter of the collecting ring of the gage is about two inches, and the ratio of collecting ring area to storage cylinder area is 1:10.



TABLE 1
No. of Rain Gages Having Various Lengths of Records

Years	No. of Gages
≥ 40	9
30-39	4
20-29	15
15-19	12
10-14	20
5-9	34
1-4	20

Many of the faithful gage readers are men who have worked on the plantations for many years and who never had the opportunity for formal education. Often they speak but little English, and so there are possibilities which cannot be overlooked for personal errors in gage readings. However, the smooth isohyetal pattern lends confidence to the general quality of the records, even though individual readings are subject to a variety of possible errors.

For the construction of the mean annual isohyetal map of Figure 2, there were available records for 116 gages in

the area of about 400 square miles, or an average of one gage per four square miles. Key maps showing locations of gages operating in 1948 have been published (4). The gage numbers adopted in the key have been used in Table 3 to help identify the currently operating stations

in the East Maui area. Old gages now discontinued do not have assigned numbers but the locations of all gages are indicated on the map of Figure 2.

A frequency distribution of length of record of gages used in this study is summarized in Table 1.

ADJUSTMENT OF RECORDS TO A LONG-TERM BASE

As in most isohyetal problems, it is necessary to adjust records of various lengths to a long-term base record. Failure to do so can distort the isohyetal pattern because certain short records may have run only during unusually wet or dry years.

The choice of a base station or group of stations is usually simple because in most areas secular changes in rainfall can occur without varying the ratios between stations. However, in an area such as East Maui, known secular changes of weather elements such as wind direction may alter interstation ratios in a systematic manner. For example, the surface wind at Honolulu has progressively changed direction during the 43-year record (10) and it is conceivable that certain stations would therefore systematically be subjected to progressively more windward exposure while other stations simultaneously would become more leeward. Examination of the records for such influences has, in the present study, been a major problem, which will be discussed below.

TABLE 2

List of the 5-Station Group Used as a Base Record

Station No. ³	Station	Mean Annual Rainfall, Inches
442	Lupi.....	177
447	Punaluu.....	126
450	Honomanu.....	221
346	Keanae.....	236
350	Paakea.....	214

It was decided that the long-term base record to be used for station adjustment and for comparison with individual records should include stations of both relatively windward and relatively leeward location, and should include both relatively wet and dry stations. This would tend to balance secular changes in one station by changes of the opposite direction in other stations. Five stations, each having records for 42 identical years, were chosen, representing at least some range in annual rainfall and nearly uniform distribution geographically about the critical high rainfall area. (Table 2.)

The rainfall averages before and after adjustment to the base group are presented in Table 3.

CONSTRUCTION OF THE ISOHYETAL MAP

The mean annual isohyetal map of Figure 2, based on the adjusted annual means, is different from the previously published maps in small but interesting ways. The isohyetal map of Maui included in the Territorial Planning Board Report (8) showed the maximum rain-

fall on East Maui to be 280 inches. The present study indicates a maximum of 400 inches located at a much more easterly position. The map of Stearns and MacDonald (7) showed two separate isohyetal maxima, the easterly one reaching 350 inches. An unpublished map of the U. S.

³ Station numbers are those used in The Key to Rain Gages in Hawaii (see reference 4).

Weather Bureau (date unknown, scale one inch = $2\frac{1}{2}$ miles), showed a long narrow area of heaviest rainfall connecting the areas where Stearns and MacDonald had drawn two maxima. The shape and position of the isohyetal maximum is of some interest because it bears on the interpretation of causes of observed rainfall.

Interpolation in ungaged areas was facilitated by the construction of profiles on which rainfall was plotted against distance, examples of which are presented in Figure 3. Numerous profiles of this kind drawn for stations in the Hawaiian Islands show a tendency for logarithmic increase of rainfall with distance (straight line plot on log paper) except in the vicinity of the rainfall maxima where the profiles round off. This feature can be seen in a number of the profiles of Figure 3. Because it helped determine the location and value of the isohyetal maximum near Wailua Iki, profile J-G-E (see Figure 3) was of particular significance.

It can be seen that this profile is nearly symmetrical in slope on both sides of the isohyetal maximum. Two straight lines drawn through the station points would intersect to the left (southwest) of Wailua Iki, indicating a maximum rainfall even higher than measured at Wailua Iki. When the crest of profile J-G-E of Figure 3 was rounded off in accordance with observed profiles elsewhere, one can read from the profile two points indicating the probable position for each isohyetal line. In this manner the position and value of the highest isohyetal line, 400 inches, was determined.

In a similar manner, profile lines were used to determine the position of isohyets in other ungaged areas, as shown by Figure 3. Such profiles also help determine isohyetal patterns in areas where, due to some unknown local factor, a particular gage may be inconsistent with surrounding ones. An example is Erewhon Makai

on Profile A-H-M. All gages except this one align themselves nicely. For this reason the Erewhon Makai record of only one year was disregarded.

A disconcerting problem was posed by the 26-year record of Honomanu Mauka. Owing to its position between Puohakamoa No. 2 (291 inches) and Wailua Iki (391 inches) it is surprising that the rainfall of Honomanu Mauka is as low as the 261 inches which the gage recorded. This relatively low value led Stearns and MacDonald to draw two closed isohyetal centers enclosing Puohakamoa No. 2 and Wailua Iki, respectively.

To seek a physical explanation for the low rainfall recorded at Honomanu Mauka, Robert P. Bruce and the writer made a field inspection of the gages along the Kailiili-Honomanu Mauka line. Each gage appeared moderately well exposed at the present time. However, Honomanu Mauka is situated at the top and near the brink of a cliff at the head of a mile-long straight reach of the deep valley of Honomanu Stream. This reach is oriented NE-SW up which the trade wind probably funnels.

The gage is placed about 50 feet southwest (leeward) of a planted line of eucalyptus trees which marks a land boundary. At the time of our inspection (June 1949) the trees immediately upwind from the gage were 25 feet high. These trees were actually sprouts from eucalyptus trunks measuring about 16 inches diameter breast height. The sprouts were 4-5 inches in diameter, and though the growth was too uniform to produce clear-cut annual rings, the age of the sprouts was estimated to be 6-8 years. There is no doubt that the eucalyptus trees were planted about at the time the trail was built and the gage installed, and about a decade ago the trees near the rain gage were cut down to provide better exposure for the gage.

The exposure near the brink of the

cliff resembles in principle that of a rain gage placed at the ridge of a peaked roof. Under conditions of prevailing trade wind, C. K. Wentworth (unpublished data) has shown that a gage at the roof peak collected less rain than normally exposed gages in the vicinity. This is due to the fact that rain tends to blow over the roof ridge and give abnormally large values on the eaves and ground to leeward.

Proceeding eastward from Puohaka-

moa No. 2, tree fern increased perceptibly and the general aspect of the vegetation indicated an increase in rainfall, not a decrease. This fact, together with the gage exposure at Honomanu Mauka, led to the conclusion that the mean annual rainfall recorded by that gage is too low. Judging from the relation of this gage to the five-station group as shown by its curve in Figure 5 and discussed below, its catch was not radically influenced by the cutting of the eucalyptus trees.

RELATION BETWEEN INDIVIDUAL GAGES

It is accepted hydrologic practice to test the homogeneity of a rainfall record by "double mass curve" plotting (2). A base station or group of stations is chosen and the annual rainfall values are accumulated from the beginning to the end of the record. The annual values for the station to be tested are also accumulated, and for each year, the accumulated value of the base is plotted against the corresponding accumulated value for the station. This results in a nearly straight line, the slope of which is the ratio of the annual rainfall of the base to the annual rainfall of the station. An example is presented in Figure 4a.

The points plotted on the diagram should vary in a random manner about the line of best fit. Any sharp break in slope is interpreted as a change in exposure or position of the station being tested.

The same principle is used here for a different purpose: to determine if there are well-defined secular changes in relations between stations. We will plot an enlarged diagram of the double mass curve, exaggerating the variation of the points about the straight line. A diagrammatic sample is shown in Figure 4b. In the present study the straight line was drawn from the origin through the point representing the latest year of record. The slope of this line is then the ratio

$$\frac{\text{average annual rainfall of station}}{\text{average annual rainfall of base group}}$$

On Figure 4b let point B represent the plotted position of accumulated rainfall of station X vs. the base group at some particular year. It can be seen that in the example, station X has accumulated rainfall at a higher than normal rate during the period from the initial year to year B. The accumulated deviation in inches of rainfall at year B is the distance \overline{BC} , which can be computed by the formula

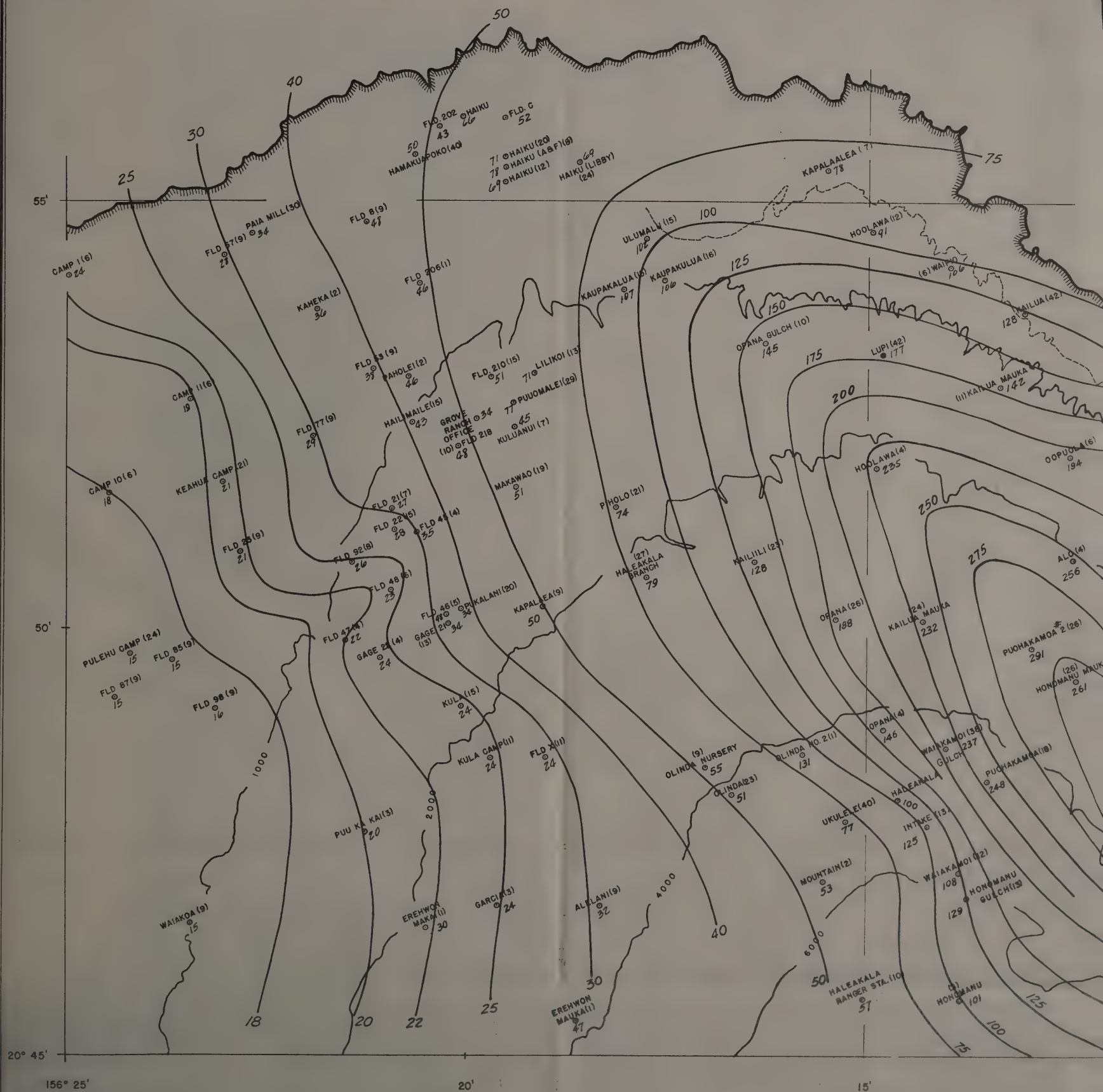
$$[S_b - (G_b \cdot R)] \cos \angle \overline{ABC}$$

where S_b = actual accumulated rain of station X at year B.

G_b = actual accumulated rain of base group at year B.

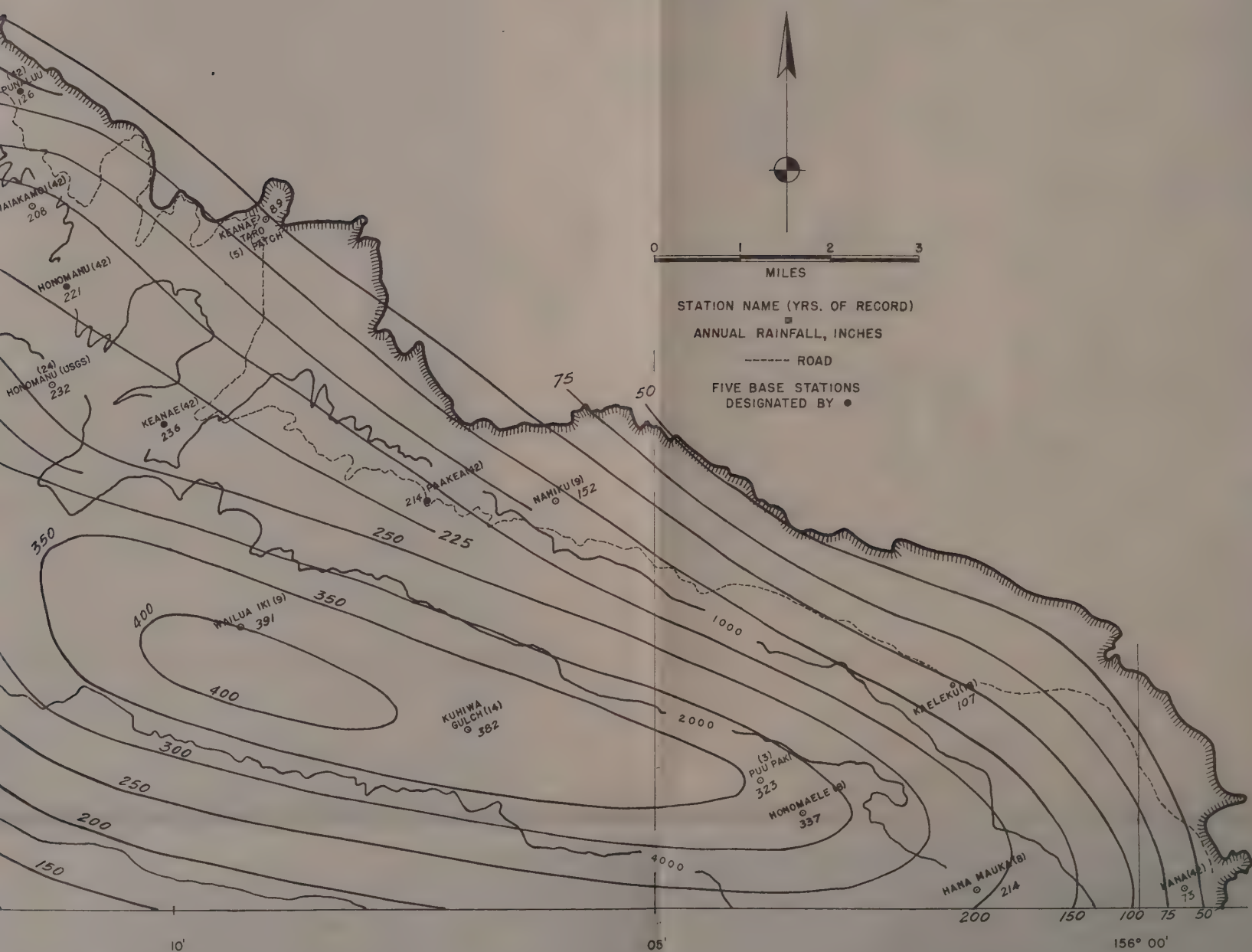
R = ratio of mean annual rain at station X to mean annual rain at base group.

Since the angle $\angle \overline{ABC}$ is constant for each year it is possible to plot a curve of accumulated deviation against years by using the distance \overline{AB} instead of \overline{BC} . Also, since the deviation curves for a number of stations will be plotted against the same time scale for interstation comparison we will divide each deviation by the mean annual rainfall of the individual station. This yields the curves in Figure 5, in which the ordinate of any point is the accumulated departure in



AVERAGE ANNUAL RAINFALL OF EAST MAUI TH.

ALL RECORDS ADJUSTED TO THE PERIOD 1907-1948
USING THE MEAN RAINFALL OF FIVE STATIONS AS THE BASE RECORD



percentage of the average annual precipitation of the respective station.

Positive slopes mean relatively large increments of rainfall at the station compared with the increment at the five-station group. Negative slopes mean relatively small increments compared with the five-station group. Comparison of slopes of curves of different stations then can be interpreted as relative rates of accumulation, and since each station curve is expressed as a percentage, the curves are directly comparable in quantitative terms.

It should be emphasized that the accumulated deviation at a given station, which is plotted as the ordinate of Figure 5, is not a measure of rainfall amounts at the station. Year-to-year variations in rainfall have been eliminated. Slopes of the lines represent rates of accumulation *relative to the concomitant accumulation at the base group*. Correlation coefficients were computed between the ratio

$$\frac{\text{rainfall for a given year at station X}}{\text{rainfall for same year at base group}}$$

and rainfall for the year at the base group. Using Hana, Waiakamoi, and Kipahulu as samples in this computation, correlation coefficients were in no case significant.

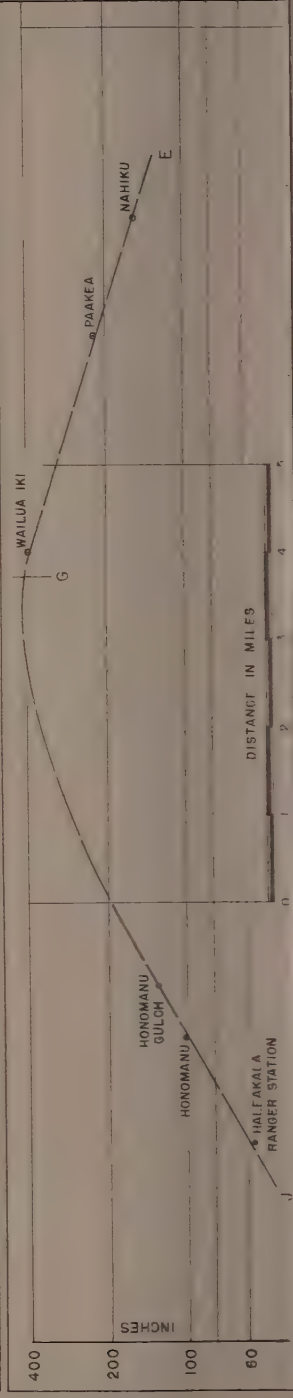
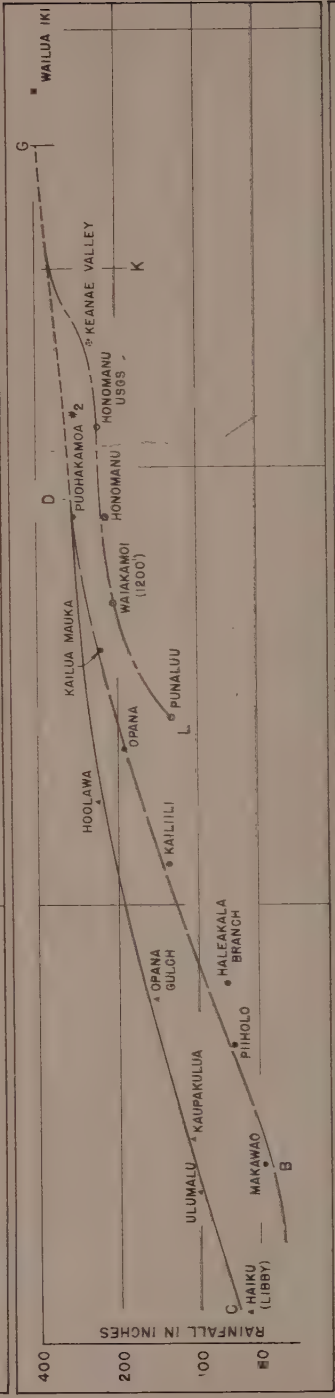
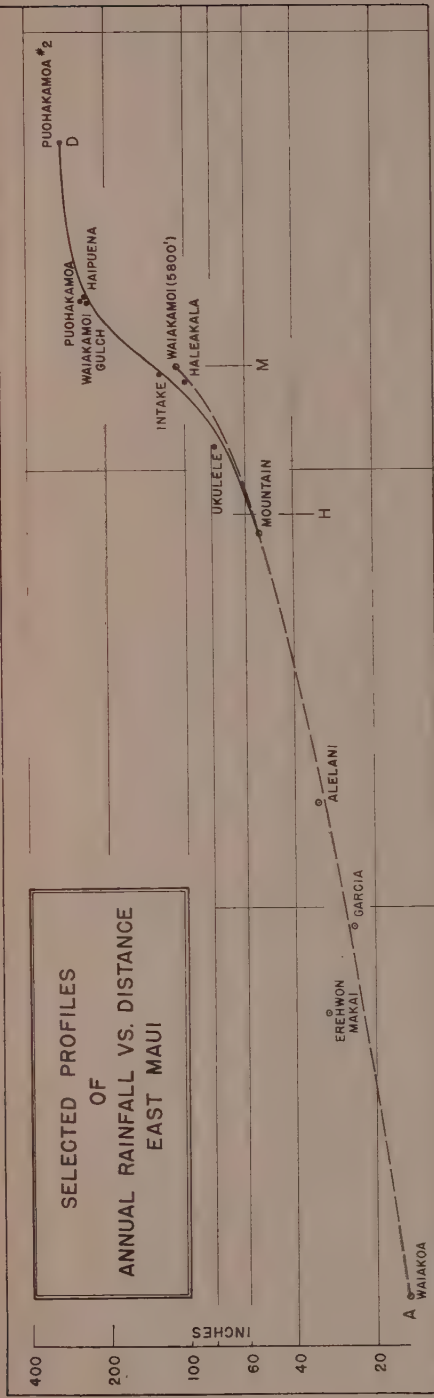
Looking at the stations in Figure 5 whose records begin in 1907, it can be seen that Puohakamoa No. 2 and Waiakamoi are the most contrasting, one increasing while the other decreases, and vice versa. Owing to the small number of stations with long records, interpretation is difficult when we confine our attention to the whole 1907-1948 record. It is somewhat clearer when the 1923-1948 record alone is inspected. Relative to the base group, the period 1923 to 1933 is marked by low rates of accumulation (negative slopes) at Puohakamoa No. 2, Honomanu Mauka, Kailua Mauka, Ukulele, and Kailua, normal rates

(near zero slopes) at Waiakamoi, and moderate (positive) rates at Hana. In the period 1933 to 1948, Hana and Waiakamoi are decreasing with respect to the base group while the other stations tend to increase.

We see that the latter stations near the coast to the north and east of the center of maximum rainfall act in an opposite manner to coastal stations to the west, and to high elevation stations west and south of isohyetal maximum. This suggests a secular trend in the position of greatest rainfall activity, that is, a shifting of position of isohyetal pattern without regard to absolute value of the isohyets. This could be caused by a downhill and easterly movement of the isohyetal pattern during the period 1923-1933 and a subsequent reverse movement.

Kipahulu lies on the southeast coast of Maui, outside the area concerned here and is probably affected in a different way by storms with southerly winds. It is interesting, however, that its deviation curve with respect to the five-station group is in phase with and similar to the Puohakamoa curve, with even larger amplitude.

If the shifting of isohyetal pattern is real, a fact which the short records do not completely establish but merely suggest, a possible explanation might lie in secular changes in the height of the trade wind subsidence temperature inversion. A lower inversion could explain the relative decrease of rain in the Ukulele-Puohakamoa No. 2 area. It is possible that this decrease in inversion height change would tend to increase relatively the rainfall at Hana. The possibility is of particular interest because of the paleoclimatic work of Selling (6). He finds evidence in the pollen bogs of Hawaii that xerophytic species grew at the top of West Maui in the early portion of "Period III," which he tentatively sug-



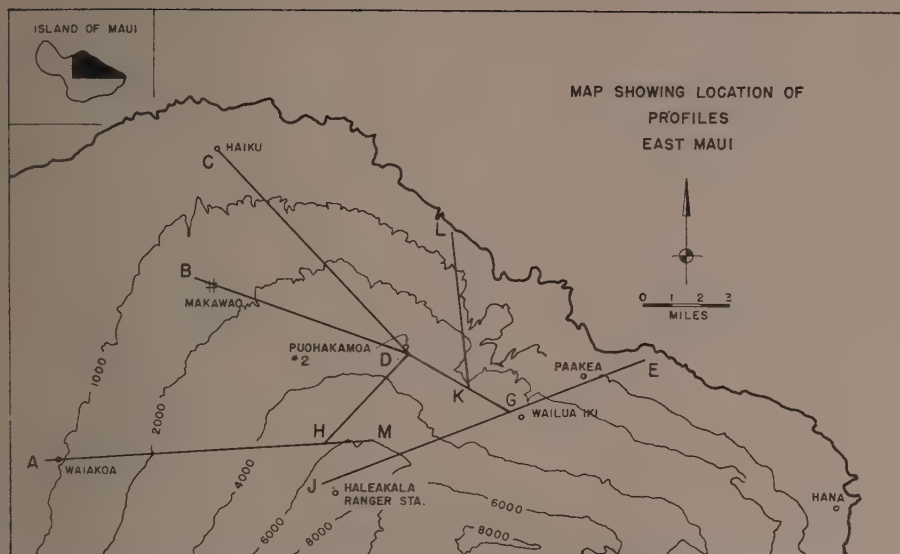


Figure 3. (Left) Rainfall-distance profiles and (above) map showing profile locations on East Maui.

gests is correlative with a geochronologically dated period of about 1000 B.C. in northern Sweden. To have xerophytes on top of West Maui, Selling suggests that the height of temperature inversion decreased until it lay near 4000 feet mean sea level. Its present height is about 7000 feet. Without attempting to discuss the details of Selling's post-glacial history of Hawaiian vegetation, it is possibly significant that there are indications within the period of rainfall record that secular changes in inversion height have occurred.

THE ISOHYETAL PATTERN

Mountains reaching high enough to penetrate the temperature inversion (whose mean height is 7000 feet) tend to split the trade wind laterally. Mountains whose tops lie below the inversion allow air to surmount their summits, as has been mentioned by Selling (6) and Leopold (3). In the latter case the maximum isohyet will lie nearly at the summit. The higher mountains receive the maximum precipitation at a lower eleva-

The secular shift of wind direction at Honolulu discussed by Wentworth (10) was examined for possible coincidence with the interstation relations discussed here, but no clear-cut correlation was observed.

The causes of the secular changes observed here are at present unknown but their description is a first step toward better understanding of the processes involved which will no doubt be of importance in paleoclimatology and long-range forecasting.

tion, about 3000 feet.

Splitting of the winds by Mauna Kea and Mauna Loa has been demonstrated by noting directions of movement of the cloud bases at various points around the mountain base (3). Similar action of the winds around Haleakala is shown by the direction of motion of cloud bases presented in Figure 6.

The dynamics of the splitting process by which the maximum rainfalls at the

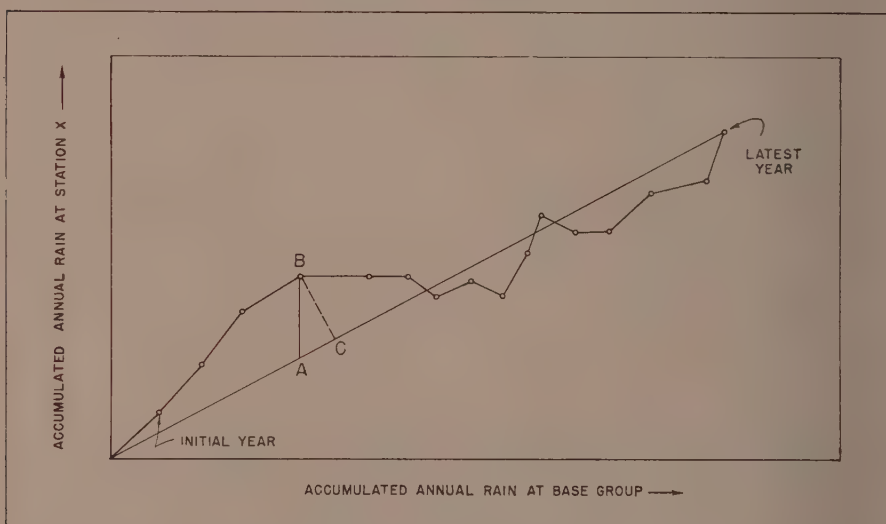
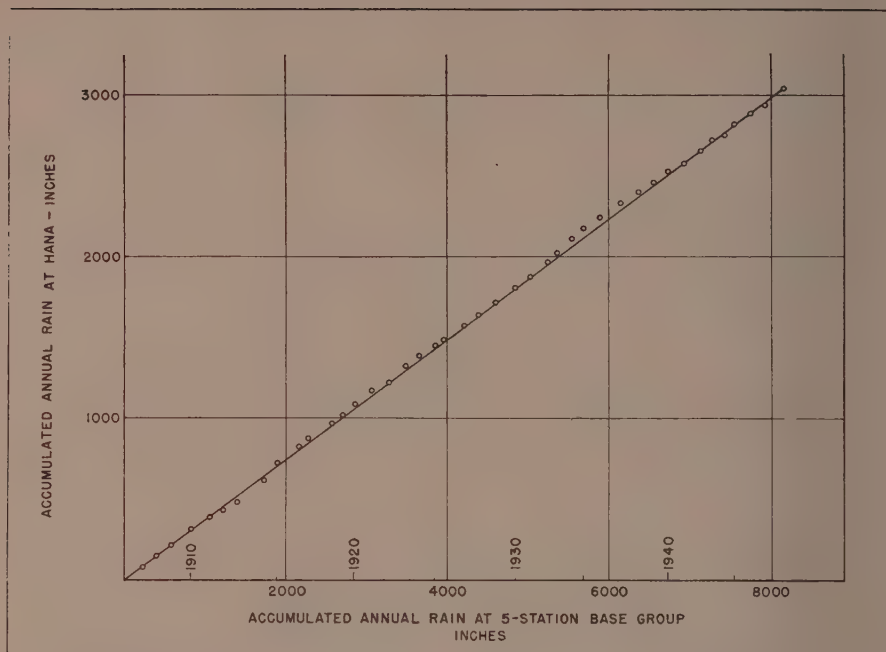


Figure 4. (Top: 4A) Accumulated annual rainfall at five-station base group in relation to accumulated annual rainfall at Hana. This type of plot is called a "double mass curve." The nearly straight line relation indicates an approximately constant ratio of annual rainfall catch at the two locations. (Bottom: 4B) Diagrammatic representation of double mass curve shown above exaggerating the deviations of the cumulative curve from the straight line.

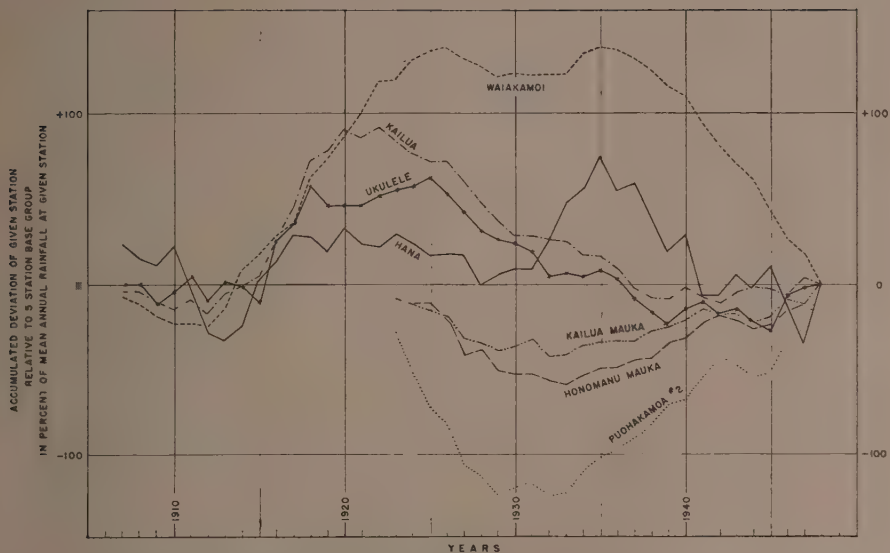


Figure 5. Accumulated deviation of annual rainfall amounts for individual stations from the accumulated annual rainfall means of an independent five-station group.

3000 feet level have not developed. It is noteworthy that the maximum rain area lies somewhat higher than the level of the normal cloud base on East Maui, which is approximately 2000 feet.

The isohyetal lines of the wet portion of East Maui (Figure 2) are nearly triangular in shape. On the NE the isohyets closely parallel the topographic contours. On the west the isohyets are perpendicular to the local topographic contours at nearly every point. On the upper slopes of the mountain, the south edge of the high rainfall zone, the isohyets are parallel to the contours. The zone where horizontal and vertical convergence combine to a maximum value is indicated by the isohyet of largest value, at the center of the northeast facing slope, and it would be illogical that wind flowing around the mountain should result in two centers of maximum rainfall as some earlier maps showed. Winds observed on the northeast slopes of the mountain tend to parallel the topographic contour. As these winds reach the place on the north

flank of the mountain where the topographic contours break suddenly from their WNW-ESE orientation to a north-south orientation, the winds will there acquire a downslope component. For this reason, it is qualitatively reasonable that the isohyets in that place should be perpendicular to the contours.

Thus in a general way the isohyetal pattern derived on Figure 2 seems in accordance with the simple topographic pattern of the north and northeast slopes of the mountain.

In the western portion of the area where the slopes of Haleakala give way to the smooth flat isthmus, there is smooth gradation of rainfall, decreasing to the west. In the vicinity of Pukalani and Pulehu Camp, there is an area of sharp bending of the isohyets, with a prong of higher rainfall jutting westward. This is a logical result of the interaction of the sea breeze and the trade wind as explained elsewhere by the writer (3). The southwesterly sea breeze meets the northeast trade along a sharp boundary

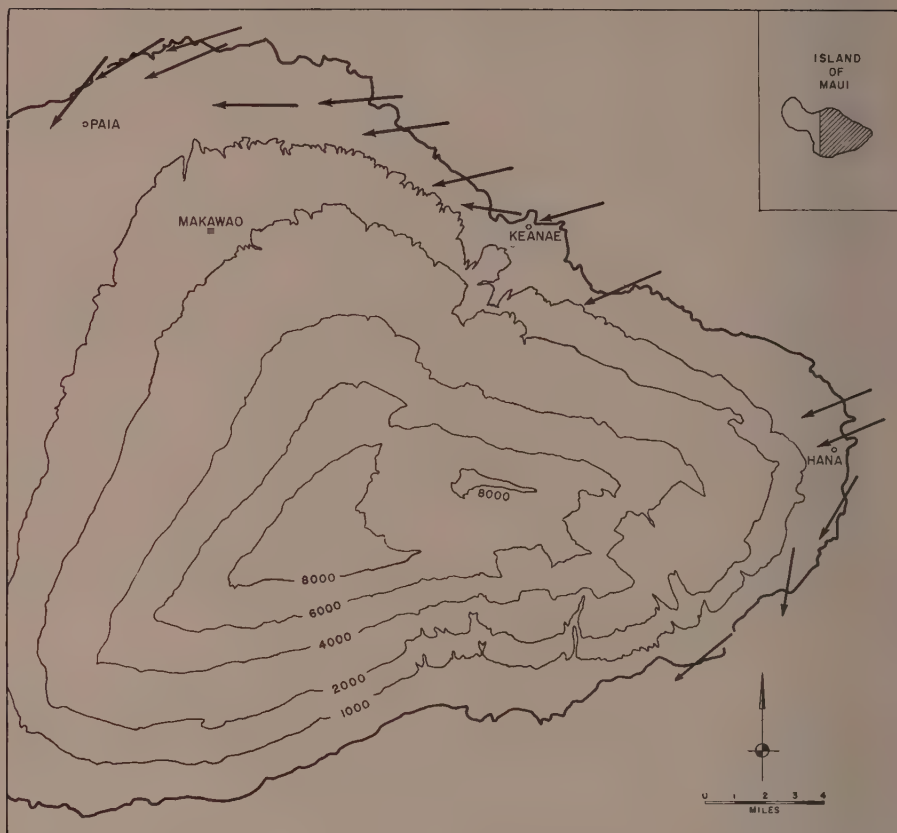


Figure 6. Wind direction at about 2000 feet as indicated by movement of cloud bases, East Maui. Wind directions represent the mean during the period mid-morning to mid-afternoon on two days of observation, July 12 and 13, 1949.

oriented ENE-WSW passing north of Pukalani Junction. The jutting area of higher rainfall there is a result of the

naulu rains caused by the interaction of the two wind systems.⁴

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the cooperation and interest of Robert P. Bruce, manager of East Maui Irrigation Company at Paia, who helped by arranging numerous field trips. George Moriguchi was of inestimable assistance in the computation, drafting, and field work. The pineapple and sugar companies of central Maui kindly furnished rainfall records for use in this study. The manuscript was read by my colleagues W. A. Mordy and C. K. Stidd who offered valuable suggestions.

⁴ The original computation sheets and the tracing of the isohyetal map have been placed for permanent record in the files of the Library of the Experiment Station, Hawaiian Sugar Planters' Association, Honolulu.

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Table 3
ADJUSTMENT OF MEAN ANNUAL RAINFALL TO FIVE-STATION BASE
(Punaluu, Keanae, Honomanu, Paakea, Lupi; mean annual rainfall of base 194.7)

No.	Station	Elev.	Period of Record	Years of Record	Mean	Ratio of Period to Total	Mean/Ratio = Adjusted Mean
330	Alalani.	3500	1940-48	9	29.4	.9158	32.1
330	Alo Gulch.	2200	1937-40	4	269.8	1.0549	255.8
400	Camp 1 (Spreckelsville).	50	1932-37	6	22.9	.9691	23.6
402	Camp 10 (HC & S).	343	1932-37	6	17.1	.9691	17.6
404	Camp 11 (HC & S).	350	1932-37	6	18.7	.9691	19.3
322	Erehwon Makai.	2200	1948	1	36.0	1.1987	30.0
324	Erehwon Mauka.	3750	1948	1	55.8	1.1937	46.6
416	Fld. 6 R.D. (Island Pine)	900	1930-34	5	118.4	.9517	124.4
416	Fld. 8 (M.A.)	290	1940-48	9	44.1	.9158	48.2
424	Fld. 21 (M.P.)	1160	1932-45	14	25.0	.9327	26.8
411	Fld. 22 (M.P.)	1400	1934-48	15	27.1	.9671	28.0
411	Fld. 23 (M.A.)	650	1940-48	9	18.9	.9158	20.6
419	Fld. 45 (Libby)	1325	1933-36	4	30.2	.8536	35.4
417	Fld. 46 (Libby)	1250	1932-37	5	45.6	.9466	48.2
405	Fld. 47 (Libby)	1100	1934-37	4	22.7	1.0324	22.0
415	Fld. 48 (Libby)	1770	1934-48	15	23.2	.9692	22.8
325	Fld. 50 (Kula, M.P.)	710	1940-48	9	34.6	.9158	37.8
417	Fld. 53 (M.A.)	120	1940-48	9	26.1	.9158	28.5
405	Fld. 67 (M.A.)	670	1940-48	9	26.8	.9158	29.3
316	Fld. 77 (M.A.)	650	1940-48	9	14.1	.9158	15.4
314	Fld. 85 (M.A.)	600	1940-48	9	13.8	.9158	15.1
419	Fld. 87 (M.A.)	1070	1941-48	8	24.4	.9348	26.1
317	Fld. 92 (M.A.)	850	1940-48	9	14.9	.9158	16.3
486	Fld. 98 (M.A.)	300	1939-48	10	39.9	.9286	43.0
421	Fld. 202 (M.P.)	700	1948	1	55.7	1.1987	46.5
430	Fld. 210 (M.P.)	1100	1934-48	15	49.6	.9671	51.3
425	Fld. 218 (M.P.)	1200	1939-48	10	44.6	.9286	48.0
487	Fld. C (Fld. B-C, M.P.)	300	1928-34	14	49.4	.9450	52.3
327	Fld. X (M.P.)	2600	1934-45	12	24.4	1.0339	23.6
426	Gage 21 (Libby)	1620	1934-46	13	32.1	.9517	33.7
320	Gage 22 (Libby)	1250	1935-38	4	25.2	1.0734	23.5
323	Garcia	2500	1946-48	3	25.5	1.0452	24.4
488	Grove Ranch Off.	1220	1925-31	7	53.7	.9877	54.4
490	Haiku (A & F)	450	1937-38	8	76.8	.9841	78.0
490	Haiku (Libby) (16-Haiku)	470	1940-44, 46	8	64.4	.9584	67.2
	(Panwela Cannery)		1925-48	24			

TABLE 3 (Continued)

No.	Station	Elev.	Period of Record	Years of Record	Mean	Ratio of Period to Total	Mean/Ratio = Adjusted Mean
	Haiku..... 20° 55' 30" N 156° 19' 30" W	530	1916-19, 1922-37	20	70.5	.9913	71.1
	Haiku..... 20° 56' N 156° 20' W	700	1907-18	12	76.0	1.1012	69.0
	Haiku..... Lat. 20° 55' 15" N Long. 156° 19' 32" W	825	1923-38	16	65.5	.9969	65.7
	Haleakala..... Lat. 20° 43' Long. 156° 15'		1936-42	7	38.4	1.0586	36.3
434	Haleakala Branch Sta.....	2160	1922-48	27	77.2	.9727	79.4
	Haleakala Pipeline.....	4900	1934-37	4	103.7	1.0324	100.4
338	Haleakala Ranger Sta.....	7030	1939-48	10	52.7	.9286	56.8
423	Haliimaile ("Station" M.P.).....	1070	1934-48	15	41.6	.9671	43.0
485	Hamakua.....	310	1907-39, 1942-48	40	50.4	1.0036	50.2
354	Hana.....	250	1907-48	42	72.7	1.0000	72.7
	Hana Mauka.....	1720	1937-44	8	212.1	.9887	214.5
	Honomaale Mauka.....	2500	1937-44	8	333.0	.9887	336.8
450	Honomanu (Honomanu Lower).....	1250	1907-48	42	220.7	1.0000	220.7
	Honomanu.....	7550	1940-42	3	96.8	.9553	101.3
451	Honomanu (USGS).....	1790	1907-18, 1937-48	24	240.9	1.0380	232.1
341	Honomanu Gulch.....	6250	1934-36, 1939-48	13	119.8	.9307	128.7
344	Honomanu Mauka.....	3100	1923-48	26	253.1	.9707	260.7
441	Hoolawa (Lupi Road).....	670	1937-48	12	89.0	.9748	91.3
	Hoolawa Gulch.....	2250	1937-40	4	247.5	1.0550	234.6
335	Intake (Waiakamoi Gulch).....	5000	1934-37, 1939-47	13	117.7	.9399	125.2
	Kaeleku.....	350	1927-44	18	106.4	.9908	107.4
413	Kahela.....	370	1947-48	2	38.2	1.0662	35.8
436	Kailili.....	2400	1926-48	23	133.3	.9661	138.0
446	Kailua.....	700	1907-48	42	127.8	1.0000	127.8
443	Kailua Mauka.....	3100	1923-44, 1947-48	24	248.3	1.0683	232.4
445	Kailua Mauka (Kailua Gulch).....	1240	1937-47	11	135.4	.9542	141.9
492	Kapalaalaea.....	450	1937-43	7	79.7	1.0185	78.2
432	Kapalaalaea (Haleakala Ranch).....	1900	1940-48	9	46.2	.9158	50.4
	Kapihula.....	1250	1907-37	31	218.2	No check between elevation and location.	213.9
	Kaupakalua.....	1050	1921-35	15	103.8	.9702	106.8
	Kaupakulua.....	1000	1922-37	16	104.8	.9928	105.6

TABLE 3 (Continued)

No.	Station	Elev.	Period of Record	Years of Record	Mean	Ratio of Period to Total	Mean/Ratio = Adjusted Mean
410	Keahua Camp (Keahua).....	520	1910-16, 1925-38	21	21.9	1.0483	20.9
346	Keanae.....	1000	1907-48	42	235.6	1.0000	235.6
	Keanae Taro Patch.....	25	1935-39	5	95.3	1.0678	89.2
	Keanae Valley.....	1850	1939-40	2	225.2	Record unreliable	249.1
	Lat. 20° 49' 18" N Long. 156° 11' 02" W						
351	Kuhiwa Gulch.....	3100	1934-44, 1946-48	14	377.7	.9897	381.6
	Kuiaha.....	456	1925-37	13	67.7	.9789	69.2
	Kula Camp.....	2200	1927-46	20	23.7	.9743	24.3
	Kuluhanui.....	1325?	1910-16	7	52.6	1.1700	45.0
	Lilikoi.....	1100	1923-35	13	67.8	.9574	70.8
442	Lupui.....	1700	1907-48	42	176.8	1.0000	176.8
	Makawao.....	5500	1907-08, 1910-26	19	58.1	1.0148	57.2
331	Mountain.....	740	1947-48	2	170.5	1.0662	52.9
	Nahiku.....	1200	1907-14, 16	9	170.5	1.1191	152.4
	Nahiku.....		1937-39	3	248.4	Gage moved; not included on map.	215.7
332	Olinda (#1, Reservoir).....	4140	1917-26, 28, 29 1932-34, 36, 37 1943-48	23	47.7	.9399	50.8
334	Olinda #2.....	4230	1948	1	157.0	1.1988	131.0
329	Olinda Nursery.....	3800	1937-44, 46	9	54.6	.9902	55.1
	Oopuola Gulch.....	1375	1931-36	6	176.4	.9081	194.2
	Oopuola Gulch.....	2075	1931-36	6	220.5	Location doubtful.	242.8
440	Opana (Opana Mauka).....	3100	1923-48	26	182.2	.9707	187.7
	Opana.....	4175	1939-42	4	142.9	.9774	146.2
435	Opana Gulch.....	1320	1937-43, 1946-48	10	149.1	1.0272	145.2
350	Paakea.....	1200	1907-48	42	214.3	1.0000	214.3
422	Paholei.....	920	1947-48	2	49.2	1.0662	46.1
406	Paia.....	125	1910-39	30	35.2	1.0241	34.4
433	Pholo (Pihiolo).....	1900	1928-48	21	71.9	.9718	74.0
427	Pukalani.....	1625	1927-46	20	33.5	.9743	34.4
315	Pulehu Camp (Pulehu).....	450	1925-48	24	14.7	.9625	15.3
447	Punaluu.....	700	1907-48	42	126.0	1.0000	126.0
342	Puohakamoa (Haipuena).....	4300	1912-20	18	253.2	1.0200	248.2
	Puohakamoa.....	1610	1922-29, 48 1931-32	2	225.5	Not included on map.	221.6
	Lat. 20° 51' 12" N Long. 156° 11' 40" W						

TABLE 3 (Continued)

No.	Station	Elev.	Period of Record	Years of Record	Mean	Ratio of Period to Total	Mean/Ratio = Adjusted Mean
	Puohakamoā..... Lat. 20° 50' 50" N Long. 156° 11' 40" W	1930	1931-32	2	278.6	Not included on map.	273.8
343	Puohakamoā #2.....	2930	1923-48	26	282.2	.9707	290.7
321	Puu Ka Kai.....	1650	1946-48	3	21.4	1.0452	20.5
	Puomalei.....	1250?	1907-21, 1924-37	29	78.0	1.0134	77.0
352	Puu Paki.....	2100	1939-41	3	311.0	.9615	323.4
	Reciprocity Mill.....	105	1937-44	8	68.2	Not within area concerned	69.0
333	Ukulele.....	5200	1907-19, 1922-48	40	77.7	1.0041	77.4
	Ulumalu.....	825	1923-37	15	100.6	.9902	101.6
340	Lat. 20° 54' 35" N Long. 156° 17' 14" W Waikamoi.....	5800	1934-37, 1939-41	12	100.3	.9327	107.5
449	Waikamoi.....	1200	1943-47	42	208.1	1.0000	208.1
336	Waikamoi Gulch.....	4250	1907-48	38	235.2	.9933	236.8
318	Waikoa.....	1100	1911-48	9	13.9	.9158	15.2
348	Wailua Hki.....	2500	1940-48	9	381.9	.9764	391.1
444	Waipio.....	700	1938-42, 1945-48 1939-41, 1946-48	6	106.9	1.0036	106.5

Controlling Molding of Rolled Oats Rat Bait with Chemicals

By R. E. Doty and C. A. Wismer¹

BRIEF

To delay development of mold in unpoisoned rolled oats required for the prebait method of rat control, the chemical para-nitrophenol has been found to be effective under high humidity—and to be acceptable to the rats.

The recommended application is 0.4 to 0.5 per cent by weight of the chemical added to rolled oats. If the p-nitrophenol is in granular form it will be necessary to pulverize the chemical before it is mixed with the grain.

The prebait method of rat control as described by Doty (3, 4) is standard practice on sugar cane plantations in Hawaii.

In using this method, unpoisoned bait is fed the rats for from five to seven days before changing to poisoned bait. This time is necessary to attract the maximum number of rats to each station. Under

conditions of high humidity, rolled oats (the standard bait in Hawaii) becomes moldy and unattractive to rats within four days, which necessitates their renewal if rats are to eat them. The extra expense of labor and materials required for this renewal operation can be saved by applying a suitable mold deterrent to the original grain.

HISTORY

Literature citing the use of chemicals to prevent molding of rat bait is limited. In 1937, Spencer (8) of the Fish and Wildlife Service reported the use of 1 per cent by weight of sodium sulfite to prevent spoilage of rat bait. In correspondence with G. Glen Crabtree (2), biochemist of the Fish and Wildlife Service Research Laboratory, we were informed that E. I. Du Pont de Nemours and Company Inc. had advised him on the

basis of limited research they had done, to try "Mycoban" (sodium propionate) for the prevention of mold in grain baits. (1, 7, 9).

On the other hand, literature on mold prevention in various phases of the food industry is voluminous. Since most of it is beyond the province of this paper, the references are not included. Chemicals such as sodium benzoate, sodium borate, sodium pentachlorophenate, and borax

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will serve as examples (5; 6, 10).

In the present studies, it was our intention to limit our research to the finding of a practical mold deterrent which

was economical, effective under conditions of high humidity, and equally important, acceptable to the rats.

MATERIALS AND METHODS

In October 1948, the present work was begun with a systematic testing of a number of possible mold deterrents. The following chemicals were compared as to their effectiveness to delay molding of rolled oats under highly humid conditions:

- Arasan (Tetramethyl thiuram disulfide)
- Atiran (Organo-mercury compound)
- Benzoic acid
- Dithane Z-78 (Zinc ethylene bis [dithiocarbamate])
- Dow 9B (Zinc trichlorophenate)
- Fermate (Ferric dimethyldithiocarbamate)
- Hyamine 1622 (Diisobutylphenoxyethoxyethyl dimethyl benzyl ammonium chloride)
- 8-Hydroxyquinoline sulfate
- Lime
- Phygon (Dichloronaphthoquinone)
- Calcium propionate
- Sodium propionate
- Para-nitrophenol
- 8-Quinolinel
- Semesan (Hydroxymercurichlorophenol)
- Sodium borate
- Sodium pentachlorophenate
- Sodium sulfite
- Sperguson (Tetrachloro para-benzoquinone)
- Zerlate (Zinc dimethyldithiocarbamate)

For the laboratory tests, weighed amounts of each fungicide were added to 100 grams of rolled oats to give 0.1, 0.3, 0.5, 0.8, and 1.0 per cent concentrations by weight. The fungicides were mixed with rolled oats in containers that revolved at 80 revolutions per minute for a period of 15 minutes. In later studies mixing at 16 RPM for 20 minutes gave a satisfactory distribution of the fungicides.

Apparatus used in the laboratory for testing the value of each fungicide for inhibiting mold growth on rolled oats is shown in Figure 1. Pans, 7 x 7 x 1 inch, used in rat control work on the planta-

tions were divided into six compartments. Grain treated with the five different amounts of each fungicide and untreated grain (check) were placed in single compartments of each pan. The pans, each covered with a tin covering as is used on the plantations, were placed in a sink with a fine water spray directed over them to maintain a high humidity. A continuous spray was achieved during each test by using an Erlenmeyer flask with an inlet and outlet tube for water. The water was regulated to enter the flask at a rate exceeding that removed by the spray, thus maintaining a constant level of water in the flask at the height of the outlet tube. The spray was produced by a spray nozzle actuated by a constant air pressure from a compressed air line controlled by an air pressure regulator.

Our method of procedure was, first, to determine materials able to withstand high humidity in the laboratory, then place the most promising fungicides in the field for further study under very wet conditions, and finally, allow the rats to indicate their preference for the five most successful mold deterrents.

In the beginning of the laboratory experiment, oats were sprayed with a suspension of mold spores in water. Later this was found to be unnecessary as the oats readily became contaminated with spores from the air.

Following this laboratory study, rolled oats treated with several concentrations of the most promising fungicides were placed in the field during a rainy period and readings on mold growth taken as soon as such growth became visible.

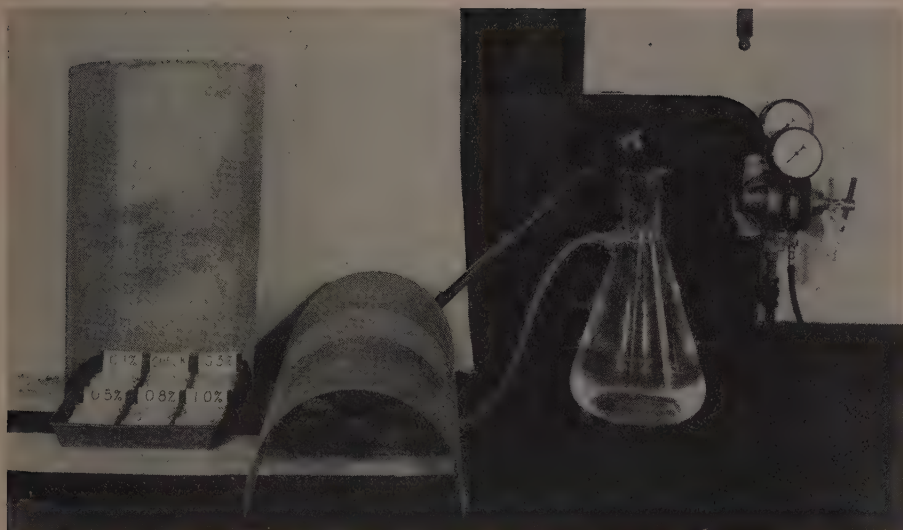


Figure 1. Apparatus for testing the fungistatic value of fungicides against molds that grow on rolled oats under conditions of high humidity. Showing from left to right, the arrangement for the different treatments in the pan, the cover in place over a pan, the Erlenmeyer flask with inlet and overflow tubes for water, and the spray apparatus connected by rubber hose to the pressure regulators on the air line at the right.

The fungicides that showed the most promise of delaying mold growth were next mixed with rolled oats and placed in stations in replicated tests in the field

to determine whether or not they were acceptable to rats. Untreated grain, serving as checks, was placed in separate stations.

RESULTS OF MOLD CONTROL STUDIES ON ROLLED OATS

IN THE LABORATORY

Most of the fungicides tested did not adequately inhibit the growth of molds on rolled oats under the highly humid conditions produced in the laboratory. Because of the success obtained with propionates for inhibiting the molding of bread when incorporated into the bread dough, calcium and sodium propionates were included in the present tests (1, 7, 9). In our laboratory studies the control of mold growth with calcium and sodium propionates on rolled oats was unsatisfactory when added in concentrations up to 1.4 per cent.

It was thought that the propionates would be acceptable to the rats, but in field tests, rats discriminated against rolled oats treated with 1.0 per cent or

more of calcium propionate.

Sodium sulfite which has been used in some rat baits to delay their molding was inferior to certain other chemicals used for this purpose in the present tests.

Some of the different degrees of mold growth obtained with several fungicides tested under very humid laboratory conditions are shown in Table 1 and Figure 2.

The chemicals 8-quinolinol, 8-hydroxy-quinoline sulfate and p-nitrophenol gave the best control of mold growth of the five fungicides shown in Table 1. Benzoic acid and sodium pentachlorophenate were unsuited for this purpose under the highly humid conditions produced in the laboratory. (See Figure 2.)

During most of test No. 4, no air pressure was available and the humidity was

TABLE 1
MOLD INDEXES* OF THE FIVE BEST FUNGICIDES UNDER VERY HIGH HUMIDITY CONDITIONS IN THE LABORATORY

TEST NUMBER																	
Fungi- cide	% Conc. by Wt.	1		2		3		4		5		6		7		8	
		No. Days Test	Under Index Fungi**	No. Days Test	Under Index Fungi**	No. Days Test	Under Index Fungi**	No. Days Test	Under Index Fungi**	No. Days Test	Under Index Fungi**	No. Days Test	Under Index Fungi**	No. Days Test	Under Index Fungi**	No. Days Test	Under Index Fungi**
Asasan	Ok.	7	5+	A.n.	6	5	R.n.	7	5	R.n.&A.n.	11++	5	R.n.&A.sp.				R.n.
	.1		5	"		3	"	"	4	A.n.	"		"	"			"
	.3		2-3	"		-1	"	"	2	"	"		"	"			"
	.8		1	"		-1	"	"	1	R.n.	"		"	"			"
	1.0		1	"		-1	"	"									
Dow 9B	Ok.	7	5+	A.n.	6	5	R.n.	7	5+	R.n.	11++	5+	R.n.&A.sp.				R.n.
	.1		5+	"		-	"	"	2+	"	"	2+	"	"			"
	.3		1-2	"		4	"	"	3+	"	"	4	"	"			"
	.8		-1	"		2	"	"	3	"	"	1	"	"			"
	1.0		-1	"		-1	"	"									"
8-Hydroxy- quinoline sulfate	Ok.							7	5+	R.n.	11++	-5	A.n.&A.sp.	4	5+	R.n.	R.n.
	.1							"	5+	"	"	2	"	"	2+	"	"
	.3							"	2+	"	"	0	"	"	1	"	"
	.8							"	2+	"	"	0	"	"	0	"	"
	1.0							"	2+	"	"	0	"	"	0	"	"
P-Nitro- phenol	Ok.							7	5+	R.n.	11++	5	R.n.&A.sp.	4	5+	R.n.	R.n.
	.1							"	5	"	"	0	"	"	5+	"	"
	.3							"	4+	"	"	0	"	"	5+	"	"
	.8							"	3	"	"	0	"	"	1+	"	"
	1.0							"	2+	"	"	0	"	"	1	"	"
8-Quinolinal	Ok.																R.n.
	.1																"
	.3																"
	.8																"
	1.0																"

Footnotes for Table 1.
*Mold Index: 0—Free from mold.
1—1-10% surface coverage by mold.
2—10-40% " " " "
3—40-60% " " " "
4—60-90% " " " "
5—90-100% " " " "

+ or - indicates over or below average for range.

**Symbols for Fungi: A.n. = *Aspergillus niger*.
A.sp. = *Aspergillus* sp. (green)
R.n. = *Rhizopus nigricans*

++Low humidity caused by faulty air pressure for this period.

***Test No. 6 is a continuation of test No. 5. Since the humidity was very high, the checks for two treatments were overgrown by *Rhizopus nigricans* on the fourth day after starting the test, and by the seventh day the mold from the lower percentages of p-nitrophenol had grown over the grain with 0.5 per cent p-nitrophenol.

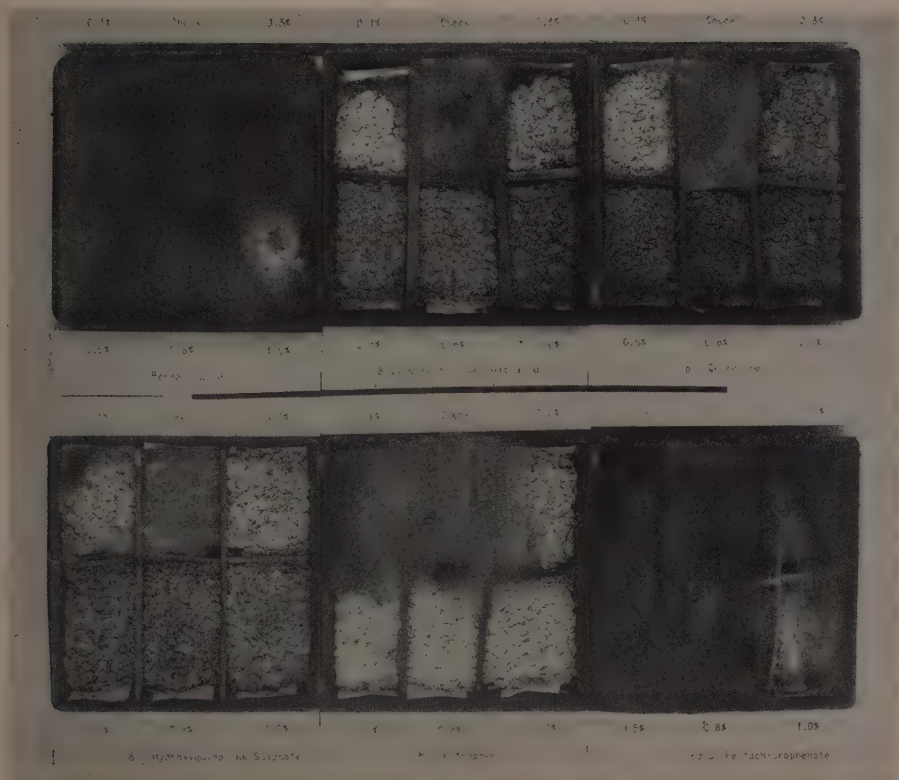


Figure 2. Different degrees of mold growth on rolled oats. These fungicide treatments in different concentrations were made in the laboratory.

too low for rapid growth of molds. Test No. 6 is a continuation of test No. 5. Since the humidity was very high, checks for two of the treatments were overgrown by the mold, *Rhizopus nigricans* on the fourth day, and by the seventh day, mold had grown over the oats treated with the lower percentages of p-nitrophenol as well. A constant spray of water over and around these stations in the laboratory gave a higher humidity than is usually found even under very wet field conditions.

A contrast in the amount of mold growth on rolled oats untreated and with oats treated with a 0.5 per cent concentration of p-nitrophenol, technical grade, is shown in Figure 3. After a period of six

days in the laboratory, the treated rolled oats remained free from mold growth while that untreated was completely overgrown with mold. The darkened area on the edges of the p-nitrophenol treated oats (Figure 3) is mold mycelium growing from the untreated oats over the low partitions between the checks and the treated rolled oats. This fungus was not established on the treated oats.

IN THE FIELD On January 27, 1949, the five most promising chemicals from the laboratory tests were mixed with rolled oats and were placed, together with untreated oats, in regular field stations in a heavy growth of hono-hono (*Commelina nudiflora*) on Tan-

talus at 1600 feet elevation. Very wet weather prevailed at this elevation. It was necessary to cover each pan with $\frac{1}{4}$ -inch hardware cloth to prevent rats from eating the grain during the test. Snails and slugs gave some trouble by crawling through the screen and eating the grain.

Notes were made on February 18,

1949, after an exposure of 22 nights and are given in Table 2.

This test indicated that para-nitrophenol, 8-quinolinol, and 8-hydroxyquinoline sulfate were about equally efficient as mold deterrents, with Dow 9B following, and Arasan distinctly inferior but still infinitely better than the checks which were completely rotted.

RAT ACCEPTANCE OF MOLD DETERRENTS

MANOA

ARBORETUM

To test the acceptance of rolled oats treated with different concentrations of fungicides as against the check, standard rat stations were established in the field at the Manoa Arboretum. Arasan, Dow 9B, 8-hydroxyquinoline sulfate, p-nitrophenol and 8-quinolinol in concentrations of 0.1, 0.3, and 0.5 per cent were added to rolled oats for these tests. Each station consisted of one pan of each concentration of a fungicide plus a pan with

untreated grain. Each treatment was replicated six times. Consumption, in grams, of untreated and treated oats for each concentration eaten for a nine-day period is illustrated in Figure 4.

The results of this test show that acceptance of rolled oats treated with Dow 9B and p-nitrophenol relative to untreated oats, was greater than oats treated with Arasan, 8-hydroxyquinoline sulfate or 8-quinolinol.

It is evident from Tables 1 and 2 that

Figure 3. Differences in mold growth on rolled oats not treated and on those treated with a 0.5 per cent concentration by weight of technical grade p-nitrophenol. The rolled oats treated with p-nitrophenol were free from mold after six days under conditions of very high humidity in the laboratory.



P-NITROPHENOL (0.5%): TREATED VS UNTREATED

TABLE 2
Mold deterrents on rolled oats subjected to wet weather on Tantalus, Oahu.

Fungicide and Concentration		Mold Index*	Notes
Arasan —	0.1%	2	Mold colonies present; brown and spoiled at edges.
	0.3%	3	Mold colonies covered 50% of area; smells bad.
	0.5%	2	" " " 35% " " ; scattered.
Dow 9B —	0.1%	2	Moldy at edges only; center is O.K.
	0.3%	1	Moldy on bottom where slugs ate up bait.
	0.5%	0	No mold—all good.
X—Check		5+	Completely covered with blue mold—rotten.
P-nitro-phenol	0.1%	0	Perfect condition; slightly yellow color; edges browned slightly where it got wet; not spoiled.
	0.3%	0	Perfect condition; slightly yellow color.
	0.5%	0	" " " ; " " " "
8-Quinolol	0.1%	0	Turned brown but in perfect condition.
	0.3%	0	" " " " " " "
	0.5%	0	" " " " " " "
8-Hydroxy-quinoline sulfate	0.1%	0	Light brown color; perfect condition.
	0.3%	0	" " " ; " " " "
	0.5%	0	" " " ; " " " "
X—Check		5+	Completely covered with blue mold; very rotten.

*Mold Index: 0—Free from mold.
1— 1-10% surface coverage by mold.
2—10-40% " " " "
3—40-60% " " " "
4—60-90% " " " "
5—90-100% " " " "

+or— indicates over or below average for range.

Note: Para-nitrophenol becomes a yellow color when dissolved in water while 8-quinolinol and 8-hydroxyquinoline impart a brown color.

p-nitrophenol is more effective than Dow 9B for controlling molding of rolled oats.

Some of the differences in consumption for different treatments within a station have been observed to be due to positional effects of the pans, i.e., in most instances the grain in a pan in line with a rat tunnel in the grass will be eaten more than grain in pans less favorably located. In order to compensate for this positional effect, pans from which the greatest amount of grain was consumed were exchanged at the time of the first two readings with pans from which the least amount of grain had been eaten.

To further test the acceptance of rolled oats treated with the above chemicals, 1 per cent mixtures of the fungicides with rolled oats were placed in stations without checks. One pan of each treatment was placed at each station so that the rats could choose the treatment most palatable to them. Untreated grain was not included in this test. The percentage of fungicide was increased beyond that

which was to be recommended for field use in order to more easily eliminate those chemicals least acceptable to the rats.

Results from six replications of these treatments are illustrated in Figure 5.

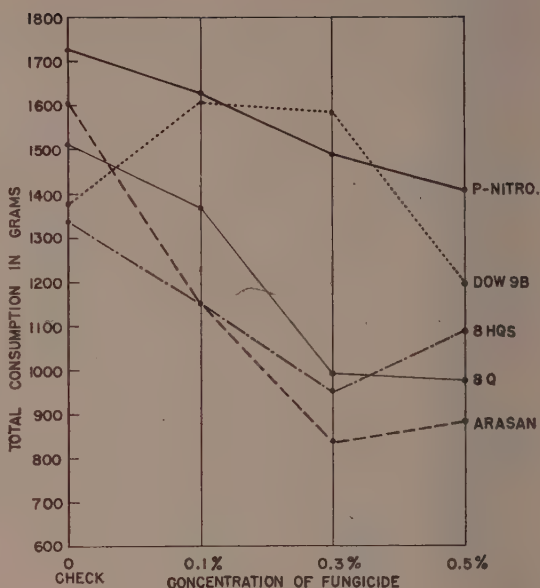
Rollled oats treated with p-nitrophenol were the most readily eaten followed by those treated with Dow 9B. The chemicals 8-quinolinol and 8-hydroxyquinoline sulfate were less acceptable as food to rats.

TESTS AT WAIMANALO To further test this fungicide as to whether there would be discrimination against it by the rats, a field test was conducted at Waimanalo with untreated rolled oats versus oats treated with 0.5 per cent p-nitrophenol. Stations of treated and untreated grain were spaced alternately at about 45 feet. Total rolled oats eaten in each treatment for 23 replications are illustrated in Figure 6.

Rats were sufficiently abundant in

Figure 4. Graphic presentation of the total consumption of untreated rolled oats compared with rolled oats treated with 0.1, 0.3, and 0.5 per cent of five fungicides.

this abandoned cane area to give reliable comparisons. During the 10 days of the unpoisoned period, stations having 0.5 per cent of p-nitrophenol averaged 1.6 per cent better consumption than check stations. This difference is the result of pure chance variation. When poison was placed in the oats, there was 4.7 per cent difference favoring p-nitrophenol over check. This small difference has no statistical significance.



CONCLUSIONS

- Para-nitrophenol was found to be an excellent mold deterrent for rolled oats used in the prebait method of rat control, as determined in a series of tests conducted in the laboratory and in the field.
- The addition of 0.5 per cent para-nitrophenol in the unpoisoned and poisoned grain did not affect the consumption of rolled oats by rats.

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Figure 5. Graphic presentation of the total consumption in grams of rolled oats treated with 1 per cent of five fungicides.

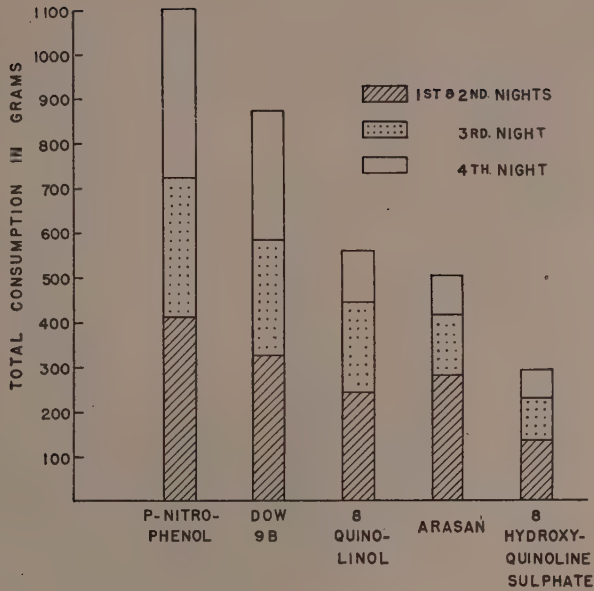
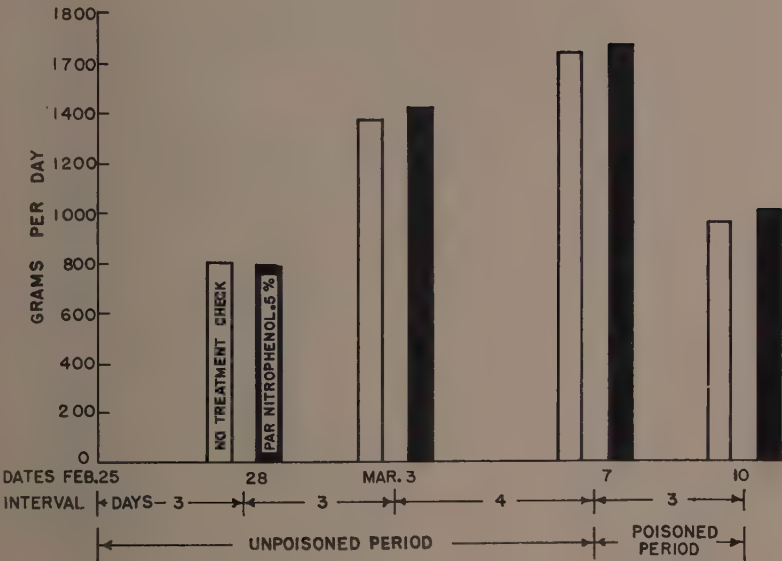
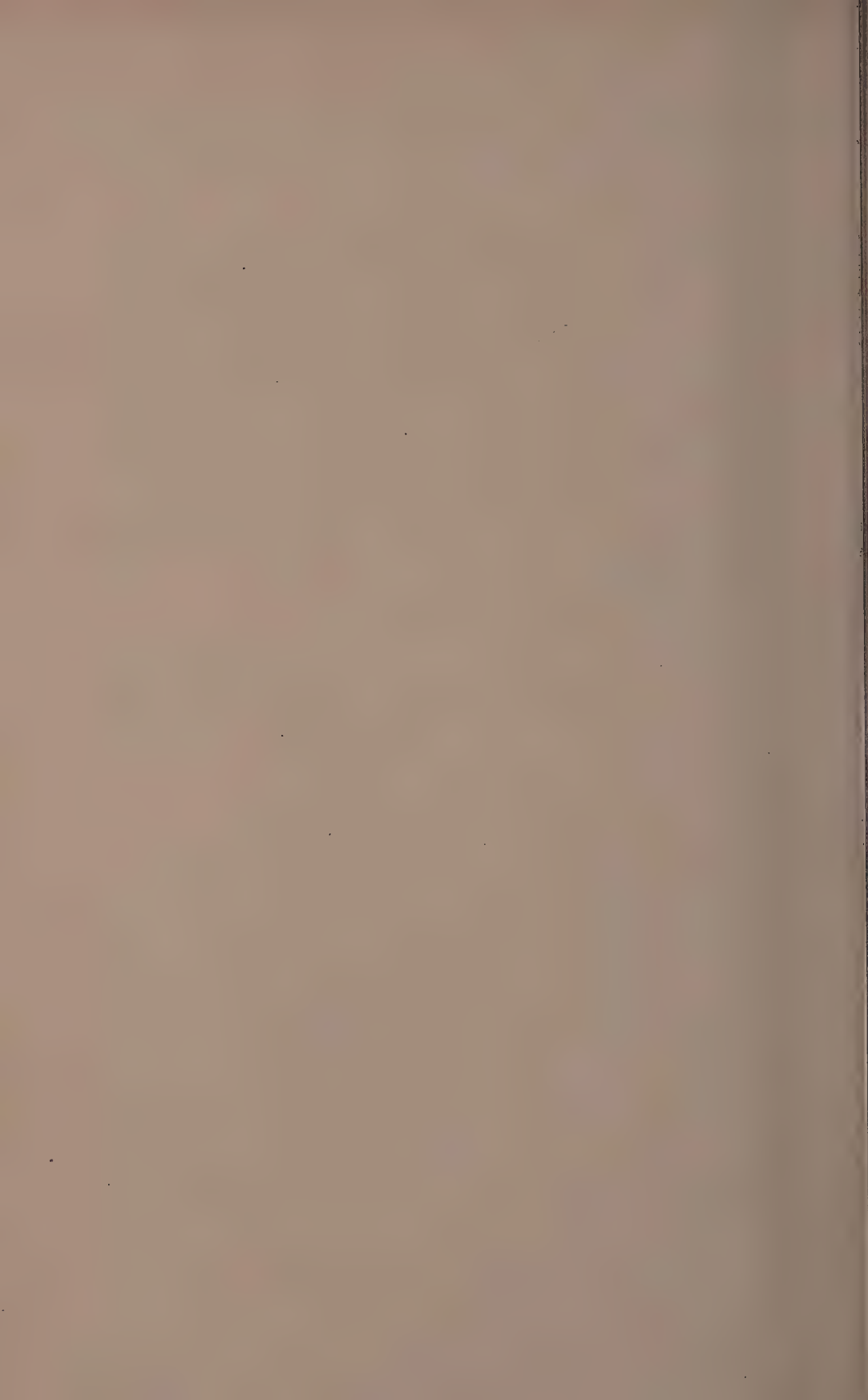


Figure 6. The average daily total consumption, in grams, of para-nitrophenol treated oats compared with untreated check oats, from 23 pairs of feeding stations.





Compound and Single Clarification Compared at Kohala Sugar Company

By H. A. Cook and M. M. Kilby¹

The Kohala Sugar Company, in cooperation with the Experiment Station, conducted a comparison of compound (Petree-Dorr) and single clarification in the factory throughout the 1948 season. Kohala has been operating with the compound clarification system for about 10 years and has likewise been producing sugars of better than average refining characteristics, i.e., filtration rates of 70 to 80 and crystal colors satisfactorily below the C. and H. standard of 7.0° Stammer. The question has arisen as to what part compound clarification had in producing the sugars with such good refining qualities, especially in view of the fact that before introduction of compound clarification and Dorr clarifiers in the district, the Kohala area had produced some very poor refining quality sugars and had resorted to sulfitation or other procedures to improve clarification and the refining quality of their raw sugars.

Operations during the 1948 crop consisted of alternating for monthly periods on compound and single clarification, the changes between the two types of clarification being coincident with the monthly stock-taking period.

A study of the figures given in Table 1,

comparing four months of operation with compound clarification and four months with single clarification, reveals no significant differences in results. Any slight advantages noted in the figures for one month are largely nullified by those of a succeeding month.

Such pertinent figures as purity difference between crusher juice and syrup are within 0.2; sugar filtration rates averaged within 2.6 points of each other and sugar crystal colors within 0.6° for each period. These variations are almost within the limits of sampling and laboratory errors even for the large number of determinations they represent.

Clarified juice turbidity, filter cake loss, pounds lime per ton cane, pan purity drops, and final molasses purity and other averages are all practically identical for the two types of clarification. To have effected an increase in recovery of even one point would have required at least one point higher purity in syrup, or a reduction in molasses purity of two points, neither of which was realized.

On the basis of these results it is concluded that there are no significant advantages in favor of compound over single clarification under Kohala conditions. The extra costs involved in

¹ H. A. Cook is associate technologist and M. M. KILBY, former assistant technologist, Experiment Station, HSPA.

operating and maintaining additional pumps, pipe lines, and equipment are, therefore, not justified.

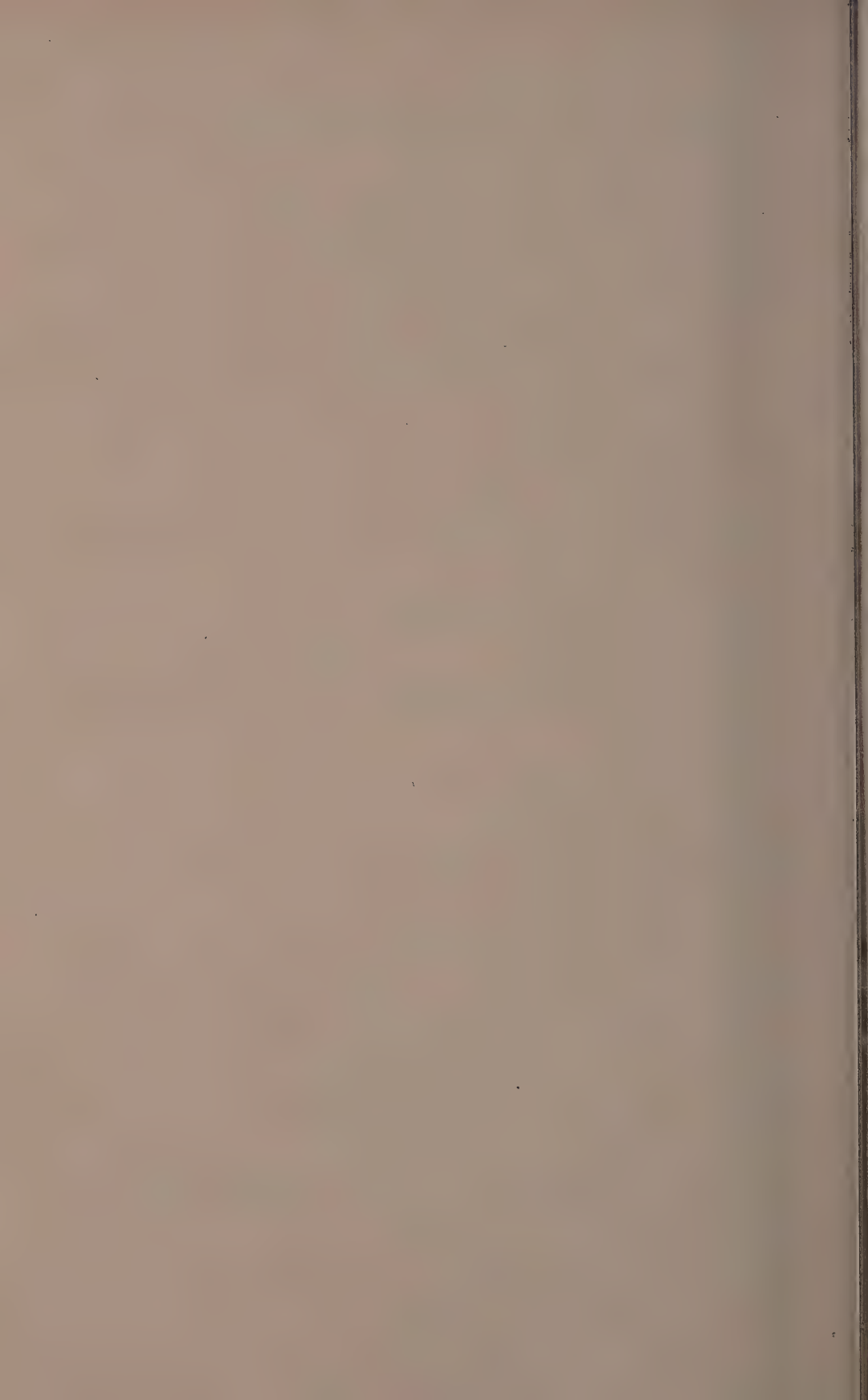
These results are in agreement with those of a previous comparison of compound versus single clarification² conducted at Hamakua Mill Company factory in 1937. During this experiment the secondary juices were limed to a high pH, as was recommended at that time,

instead of the lower pH that was later recommended and has been in use at Kohala. The conclusion from the Hamakua experiment was that, "under conditions found at Hamakua, there are not sufficient apparent advantages (to compound clarification) . . . to justify the additional equipment or offset the greater ease and efficiency of operations in single clarification."

² Cook, H. A. Test on Compound and Single Clarification at Hamakua Mill. Sugar Technology Activities Report. August 10, 1937.

TABLE 1
DATA ON COMPOUND AND SINGLE CLARIFICATION

Dates	Trash % Field Cane	Crusher Juice Purity	Purity Difference		Clarif. Juice Turb.	Undet'd Loss %	Lime Lbs./ Ton Cane	Molasses		Purity Drops		Sugar	
			Crusher to Clarif.	Crusher to Syrup				Sucrose Purity	Purity Above Expected	Strike A	Strike B	Cryst. Color	Filt. Rate
Compound													
Apr. 5 to 24	38.5	85.69	2.53	2.02	52.0	-1.91	1.41	40.40	7.42	15.93	13.36	6.86	60.3
June 1- July 3	26.6	84.79	2.67	1.59	40.2	1.04	1.50	39.51	7.08	18.16	13.33	3.48	84.2
Aug. 2 to 28	27.1	84.46	2.53	1.91	52.0	0.44	1.67	38.91	6.34	17.11	13.66	4.15	80.8
Sept. 27- Oct. 30	34.0	86.96	2.17	1.68	56.5	-0.33	1.52	41.51	7.43	18.26	13.64	2.66	74.4
Av.	31.6	85.47	2.47	1.79	50.2	-0.19	1.53	40.08	7.10	17.37	13.50	4.29	74.9
Single													
Mar. 1 to 20	38.0	84.73	2.15	1.20	54.0	0.10	1.48	37.71	5.97	16.22	12.54	4.60	57.7
Apr. 26- May 29	29.6	86.26	2.67	1.88	43.6	0.57	1.66	41.11	8.47	16.71	12.74	4.16	73.2
July 6 to 31	30.3	84.88	1.97	1.52	51.0	0.25	1.31	39.17	6.33	18.30	14.01	3.42	79.2
Aug. 30- Sept. 25	28.1	85.15	1.92	1.68	37.0	-1.87	1.52	39.45	7.16	18.35	14.33	2.63	79.0
Av.	31.5	85.26	2.18	1.57	46.3	-0.24	1.49	39.36	6.93	17.40	13.41	3.70	72.3



Recent Developments in Sources of Nitrogen for Fertilizing Crops¹

Among new forms of nitrogen fertilizer available for sugar cane are urea, ammonium nitrate, ammonia or nitrogen solutions, anhydrous ammonia, and Urea-form.

Several of these, together with the older, more familiar sources, have shown equivalent sugar producing values when compared on an equivalent pound for pound nitrogen basis.

As far as their comparative effects on soil acidity and losses by leaching are concerned, there appears little reason for consideration of these points in Hawaii since sugar cane is not very sensitive to acid soil conditions, and tests have not shown leachable nitrates less efficient than the non-leachable ammoniates.

However, further study seems to be called for on the secondary elements of the various nitrogen fertilizers, and to determine the most economical form of nitrogen—the most costly plant nutrient for cane—a definite cash value must be arrived at for these secondary elements.

At the moment, however, the high analysis materials appear to have many economical advantages since the cost of a fertilizer includes a number of items which are figured on the basis of weight of the fertilizer rather than on its nitrogen content.

Agronomists recognize four major forms of nitrogen fertilizers—water insoluble proteid organics, ammoniacal nitrogen forms, nitrates, and soluble organic non-proteid forms. When discussing these different forms, there is a general inclination to stress certain points about them. For instance:

- That water insoluble organic forms do not leach from the soil and do not increase the soil acidity, although they are expensive and have a low total nitrogen content.
- That ammoniacals are completely available and are not easily leached,

although they do increase soil acidity.

- That nitrates are completely available and in the form of calcium and sodium nitrate tend to reduce soil acidity, but they are, however, subject to loss by leaching.
- That non-proteid organics such as urea are completely available, are resistant to leaching, and only increase the soil acidity very slowly.

I am not sure that the emphasis placed on the comparative effects upon soil acidity and on the losses by leaching needs very serious consideration in our choice of a nitrogen fertilizer for cane.

¹ A paper presented at a seminar held at the Experiment Station, HSPA, on December 17, 1948, by R. J. Borden, agronomist.

In the first place, cane is not very sensitive to acid soil conditions. We have a test in which large pots of an acid soil that had a pH of 5.3 when potted in 1933 has been cropped with sugar cane yearly since that time. Excessively heavy applications of ammonium sulphate have reduced this soil pH from 5.3 to 4.4; whereas similar applications of sodium nitrate have brought the pH up to 6.4. In spite of this great difference in soil acidity, the 1948 cane crops have produced slightly more sugar on the more acid soil, although the actual amount of difference in sugar yields is not significant; nor has it been significantly different in any of the 14 crops we have harvested.

In the second place, ammonia changes to nitrate very quickly in most of our sugar cane soils. We have records of the nitrification of two-thirds of the total ammonia from ammonium sulphate within a period of two weeks, and almost complete nitrification in six weeks, even in an acid soil. I believe Q. H. Yuen of our Chemistry Department has found similar evidence of a very rapid and complete nitrification of ammonia nitrogen within a month or six weeks.

In the laboratory we have secured over 50 per cent nitrification of ammonia within six days. And so, under our climatic and soil conditions, I cannot be very encouraged by the fact that ammonia will not leach, nor feel sorry that nitrates do leach, because ammoniacal fertilizers do not really have much of a chance to keep their nitrogen in this form very long after they are applied to our cane soils.

Nor can I be very excited about the losses of nitrogen by leaching from our cropped-cane soils. I remember that the late H. P. Agee, one of our former directors, used to point out that in a test at Hakalau, an application of only 50

pounds of N from nitrate of soda increased the cane yield 33 tons, in spite of the fact that more than 100 inches of rain fell after this nitrate was applied; there could not have been much loss by leaching in this case.

We have applied considerable amounts of nitrate nitrogen fertilizers in our irrigation waters, and the total quantity of water applied has certainly been as large as from any series of heavy rains; so we know that these large amounts of water with their absorbed nitrates have gone far below the average root system, and, yet, it is doubtful that we could have obtained the crop increases that we did get from these N applications if the N had actually been lost from the cane's root bed.

It hardly seems likely that there could have been very much N lost by leaching in a recent test at Lahaina, where 126 pounds of nitrogen, all applied at four to six inches under the seed, made 113 tons of cane in 20 months; this cane soil must have been wetted far below the active root zone many times during the growth of this crop while the field was being irrigated.

And in spite of the fact that we have made many comparisons of nitrate forms of N which leach with ammonia forms which do not leach, on many soils under heavy rainfall conditions, and on irrigated soils that get much higher single amounts of water than come in single rains, and fully as much total leaching per crop, we have not found the leachable nitrates to be less efficient than the non-leachable ammoniates. So I do not feel that we should worry too much about this matter of leaching.

I think we may be over-emphasizing the possibility that leaching of nitrates means their actual loss to the crop. We have some evidence that some very rapid biological fixation of applied N is holding it within the cane's root feeding

zone, and that this fixed N does become available to cane crops.

For example, in a recent study in which we added cane trash and nitrogen to a soil, and fallowed it from two to 12 months, sugar yields fell below those of the checks (without trash) from soils that had less than eight months of fallow, but after this eight months of fallow the yields were equal to the checks; apparently applied nitrogen which had been fixed by soil organisms did become available for the crop later in the growth period.

COMPARISON OF DIFFERENT FORMS

Nitrogen is the most costly plant nutrient we have to buy, and there is considerable variation in the price we have to pay for the different carriers. So in the choice of a nitrogen fertilizer for sugar cane we should know the relative merits and faults and the comparative efficiencies of the different forms or sources of nitrogen.

Fortunately we have a considerable amount of scientific and practical evidence to guide us in making our selection.

First let us look briefly at some of the older nitrogen materials from which we can still choose today.

SODIUM NITRATE This fertilizer (16 per cent N) has been used for a longer time and is perhaps better known than any of the inorganic N fertilizers. Most of it still comes from Chile's natural deposits, but in recent years large quantities have been manufactured from synthetic ammonia, oxidized to nitric acid and added to sodium carbonate.

At one time, 20 years ago, this natural nitrate of soda was the chief source of nitrogen used on our sugar plantations.

And, furthermore, applied N fertilizer can become tied up by soil organisms pretty fast. In a soil that carried freshly added cane trash and was fertilized with ammonium nitrate, we found that 65 per cent of the soluble N supplied was tied up and not found as water soluble N after only three days when ideal conditions for biological activity were maintained.

We also have some evidence that there can be an upward movement of nitrate nitrogen in soils which can bring the leached nitrates back into the root zones.

AMMONIUM SULPHATE The world's consumption of ammonium sulphate (21 per cent N) for fertilizer purposes has now exceeded sodium nitrate, and accounts for about half of the total N used in commercial fertilizers. Most of that used in the United States is a by-product of coal distillation, but considerable quantities are also being made from ammonia, gypsum, and carbon dioxide.

Ammonium sulphate accounts for the major part of the nitrogen fertilizer we use on our cane crops today.

CALCIUM NITRATE This (15.5 per cent N) was the first synthetic nitrogen fertilizer on the market, but it was never satisfactory because it was so hygroscopic—it would dissolve in one's hand. It blistered the skin and shrank the shoe leather of workmen who handled it. And it would not flow freely from a fertilizer distributor when the relative humidity was even as low as 46 per cent. But the present-day product has been greatly improved; it is now granulated and free from dust. It is made chiefly in Norway, none being made in the United States today.

Calcium nitrate has had only limited use in Hawaii, chiefly on the heavy clay soils at Kekaha and Ewa, in the hope that its lime content would improve the physical condition of these tight soils.

CALCIUM CYANAMIDE . This black, manufactured product (21 to 25 per cent N) which furnishes about 5 per cent of the nitrogen consumed by world's agriculture, is obtainable in both an oiled-powdered form and in a large granule form. It is easy to handle from newly opened bags, but it absorbs water slowly when exposed to the atmosphere. In the soil it changes to urea, especially if the soil is acid.

Calcium cyanamide has been extensively used by Louisiana sugar planters, but has not been used in field practice here, chiefly, I believe, because it has not been offered on a competitive cost basis.

So much for the older sources of nitrogen. Now let's look at some of the newer sources. In considering their possibilities we should bear in mind these points:

- They must be cheap and effective, and concentrated so as to save transportation costs and labor for handling.
- They should be easy and convenient to handle, and should remain in good and stable condition when stored.
- They should meet the varied demands or needs of the crop, i.e., be available at the critical growth periods, both early and late.
- They should not be harmful to the physical conditions of the soil or cause wasteful losses of chemical nutrients from the soil, or produce soil conditions undesirable for the maintenance of a permanent soil productivity. In fact, their effect should be just the reverse.

UREA First of the new materials is urea (46 per cent N), a white crystalline product, made from ammonia and carbon dioxide gas under high pressure. Chemists classify its nitrogen as a synthetic non-proteid organic nitrogen. In soil it is quickly converted into ammonium carbonate.

Because urea absorbs water from the air and becomes difficult to handle, a product called *Uramon* (42 per cent N) is preferred unless the urea is to be used in solutions. In *Uramon* the crystal urea has been coated with about 2 per cent inert mineral and organic materials (such as rock phosphate and finely ground cocoa hulls). *Uramon* is now a real competitor in the nitrogen fertilizer market because it is cheap and becomes completely available to crops through conversion in the soil to the ammonia and nitrate forms.

Some *Uramon* has been used here on sugar cane, chiefly at Ewa, I believe.

A precipitated product from a mixture of solutions of urea and calcium nitrate, called *Calurea* (34 per cent N) has also been used here experimentally. It has most of the physical properties of urea.

AMMONIUM NITRATE Back about 1935, a solution of ammonium nitrate and ammonia was used in ammoniating superphosphate, but it is chiefly within the last five or six years that a suitable ammonium nitrate product (33.5 per cent N) has come on the market in quantities sufficient to compete with other sources of nitrogen.

Much of this relatively new commercial N fertilizer is being produced in many of the Army's ordnance plants that recently produced it for war purposes, but not much of this Army product has come into the domestic fertilizer market as yet. Some 250,000 tons a year is all going to Germany, Japan, or Korea to bolster foreign agricultural production.

Commercial ammonium nitrate is very soluble, and is in fact, more than twice as soluble as ammonium sulphate and nitrate of soda. Fifteen to 15½ pounds of ammonium nitrate can be dissolved in a gallon of water at room temperature, as compared with six pounds of ammonium sulphate, or seven pounds of sodium nitrate, or 8½ pounds of urea.

Ammonium nitrate is very hygroscopic under humid conditions and starts to absorb moisture from the air at about 59 per cent relative humidity. Its tendencies to cake and to absorb water have been reduced considerably in some of the new products, by making it in larger granules, and by conditioning them with a coating of diatomaceous earth or very fine clay, and further treating with a water-repelling agent. So present difficulties in handling ammonium nitrate are not as great as formerly, especially if it is applied immediately from the newly opened water-proofed bags it is now shipped in or applied as a solution.

We have used considerable ammonium nitrate for our sugar cane in the past few years, and will most likely use more if the present price differential between nitrogen in this material and in other carriers continues. It is by far the cheapest N we have on our local market today.

AMMONIA OR NITROGEN SOLUTIONS Ammonium nitrate is also dissolved in aqueous ammonia to make nitrogen solutions. Aqueous solutions of ammonia and urea are also used for nitrogen solutions. These solutions are concentrated and carry 37 to 45 per cent N, including 13 to 25 per cent of N as free ammonia. They are cheap and provide an easy means of adding free ammonia to mixed fertilizers without the necessity of first converting it into salts. They are now used chiefly by man-

ufacturers of mixed fertilizers because of the difficulties experienced by individual users in handling liquids of high vapor pressure in large tanks.

Nitrogen solutions now comprise a little more than a third of the total commercial output of fertilizer nitrogen in the United States.

The most popular nitrogen solution is a solution of ammonia and urea which is sold as *Urea Ammonia Liquor* or *U A L 37*, for in its manufacture some nitrogen compounds of the urea-formaldehyde class are produced, and these slowly soluble N compounds were shown to be a good source of nitrogen for crops in experiments conducted by McCool in 1941 at the Boyce Thompson Institute of Plant Research. Availability of this form of nitrogen does not change in storage and it compares favorably with other insoluble nitrogen materials.

ANHYDROUS AMMONIA A discussion of this nitrogen fertilizer material (82 per cent N) was thoroughly reviewed at the 1948 HST meetings by W. P. Naquin of Waialua Agricultural Company and by the Shell Chemical Company representative; so I shall try not to repeat much of what they told you about anhydrous ammonia.

As you know, it is a liquid ammonia under pressure and changes to a gas when released to the atmosphere, in the soil or in irrigation water.

It was used experimentally at Pioneer, Ewa, and Lihue as far back as 1930, and gave results which were quite comparable to those secured from standard sources of N, but until this year it has never been offered to us at a cost applied in the field that would make it a competitor with the solid N fertilizer salts.

Following four years of intensive research by Dr. W. B. Andrews,² associate

² Miss. Agr. Col. Ext. Bul. 448.

in soils, and his co-workers at Mississippi State College and a vigorous testing and demonstration campaign by Shell Chemical Company in California and Arizona, it was given a big boost in 1947 and now seems to be ready to take a prominent place in the nitrogen fertilizer market. At present it has only a minor place in the United States market, amounting to less than 4 per cent of the total nitrogen used.

Twenty years ago, Clint Owen, then manager of Pacific Guano & Fertilizer Company, told me that anhydrous ammonia would eventually take over the nitrogen fertilizer market in the Islands from other sources of N. It has been slow to come but perhaps it is coming.

The critical problem involved in the use of anhydrous ammonia is the rapidity of sorption by soil immediately after its application, and the extent of loss by diffusion into the atmosphere.

M. L. Jackson and S. C. Chang³ of Purdue have reported that this loss was not an important factor. In their studies of anhydrous ammonia retention by soils, they found that ammonia injected at a depth of one to two inches is practically all absorbed instantly, even in a coarse textured soil; that even at the rate of 600 pounds of N per acre, 95 to 100 per cent of the gaseous ammonia was held in a moist soil when the placement was two to four inches deep. They point out that since there was such a slight difference between sorption in air-dry soil as compared with field-moist soil, this soil moisture factor can be disregarded in field practice. The fact that air-dry soil sorbed almost instantly 13 times its air space porosity volume of ammonia gas illustrates the tremendous power of a soil for preventing losses of gaseous ammonia applied as fertilizer.

I believe that the Citrus Experiment

Station at Riverside, California, has found losses from distribution in water while irrigating citrus to be less than 10 per cent.

The research work of experiment station groups at Mississippi and of Shell Chemical Company in California gives much confirmatory evidence of the fact that gaseous losses from anhydrous ammonia in soil or water are negligible.

In the Mississippi tests,⁴ crop yields from 32 pounds of nitrogen in the forms of ammonia and ammonium nitrate were not significantly different in wet years, but in dry years when a surface application of ammonium nitrate was positionally unavailable, because there was no soil moisture at the surface to dissolve it, deeper placement of ammonia, four to five inches deep where there was some soil moisture, produced higher yields.

Anhydrous ammonia when properly released into irrigation waters is absorbed instantly. Some ammonia reacts with dissolved mineral salts in water and forms salts of ammonia; the rest forms ammonium hydroxide. Anhydrous ammonia released directly into the soil combines with the clay fraction to form an ammonium clay. Hans Jenny of California reports that even dry clays readily take up ammonia from vapors containing ammonia molecules, but that these molecules are loosely held and are easily removed by aeration. He also says that this ammonia which is adsorbed on clays can be readily utilized by plant roots and that it is also easily nitrified.

Getting into the soil solution, ammonia becomes ammonium hydroxide and generally takes up carbon dioxide to form ammonium carbonate.

I think you may be interested here, in the results of studies made by Jenny and co-workers in California,⁵ on the com-

³ Amer. Soc. Agron. Jour. 39(7):623.

⁴ Miss. Agr. Col. Ext. Bul. 448.

⁵ Hilgardia. 16:9. 429.

parative behavior of ammonia and ammonium salts in soils, for their work throws considerable light on controversial questions relating to the effects of these materials on crop production.

Promoters of anhydrous ammonia emphasize the fact that their product does not contain anions such as sulphates or chlorides which might remain in soil as an undesirable residue. Theoretically, Jenny points out that continued use of ammonium sulphate might ultimately increase the sulphuric acid concentration of the soil solution to such an extent as to reduce plant growth. But in practice such conditions will not be common, because rains and/or heavy irrigations will displace concentrated solutions to depths below most roots; moreover, since soils contain some exchangeable calcium, the ammonium sulphate may be converted into ammonium clay and gypsum—and gypsum is not toxic to plant roots.

According to some claims, ammonia liberates substantial amounts of exchangeable potash and phosphate in the soil. Jenny's results substantiated this claim as far as potash is concerned but also showed that ammonium sulphate was more effective in this respect than ammonia. He regards this action of little importance, however, since potash held on clay in exchangeable form is readily available to plant roots.

Jenny also points out that ammonia, owing to its alkaline reaction, may possibly release more phosphate than ammonium sulphate from soils in which the phosphate is tied to aluminum or iron, but would adversely affect this release of phosphate from a soil in which phosphate exists as calcium phosphate.

In contrast, ammonium sulphate with its slightly acid reaction would have just the opposite effect on phosphate availability; it would lower the availability of phosphate from iron and aluminum phosphates, and increase the availability

of phosphate from calcium phosphates.

These California studies also show that penetration of ammonium hydroxide in soils is conditioned by soil texture. In coarse textured soils, ammonia distributes itself rather uniformly through a depth exceeding six inches, whereas in clays and clay loams it is practically all fixed in the top two inches. Ammonia and ammonium sulphate behave very much alike in this respect, although in acid soils ammonium sulphate penetrates deeper than ammonium hydroxide. Soil structure also affects ammonia penetration, for in soils which crack upon drying, the irrigation water that fills these cracks will carry dissolved ammonia into them for a considerable depth.

UREA-FORM The problem of providing nitrogen materials of low solubility has been studied before, and we have had the ammoniation of peat and of superphosphates.

Need for nitrogen fertilizers of low solubility which will release N at rates approximating crop requirements has long been recognized. Formerly this need was best supplied by natural organic fertilizers, but natural organics are costly and a considerable percentage of their total N is not available; the remaining portion is converted into mineral forms in a relatively short period. These considerations indicate the need for synthetic nitrogen fertilizers of low solubility, with controlled rates of availability, and also high total availabilities.

Several such materials have now been produced in small quantities in the USDA labs at Beltsville, by the reaction of urea and formaldehyde. These products, which are not yet commercially available, have been given the name Urea-form. They differ in respect to surface areas, solubilities, and nitrification rates which depend on the respective urea/formaldehyde ratios. They carry 36

TABLE 1 — EFFECT OF SOURCE OF NITROGEN ON YIELDS OF BERMUDA GRASS

Clip No.	No. of Days Between Clips	Cumulative	Average Yield (gms./pot)			
			Amm. Sulphate		Urea-form	
			From clip	Cumulative	From clip	Cumulative
1	28	28	.89	.89	.57	.57
2	36	64	5.95	6.84	3.37	3.94
3	65	129	.98	7.82	4.32	8.26
4	83	212	1.62	9.44	3.22	11.48
5	103	315	1.28	10.72	2.05	13.53
		In roots and crowns		19.76		25.46
		Total dry matter		30.48		38.99
		Total nitrogen recovery		55.2%		56.1%

to 38 per cent nitrogen, have a 4 per cent moisture content, and are much less soluble than commercial nitrogen fertilizers in present-day use. They can absorb considerable amounts of moisture without changing their physical condition, and so will make a high-analysis, anti-caking and conditioning agent for mixed fertilizers.

In nitrification experiments in the Beltsville laboratory, the availability of their nitrogen was roughly proportional to their solubility in water.

Most promising of these products as sources of slowly available N are those with U/F ratios of 1.2 to 1.4. After an initial period of about four weeks of low activity, they nitrified slowly and at substantially constant rates for about three months, and then at slightly reduced rates for another two or three months. In comparison, ammonium sulphate was nitrified within a period of four weeks; in fact, 80 per cent of it within two weeks.

In practical use, the application of Urea-form may be supplemented if necessary with a small amount of a quickly available N to supply early demands of the initial growing period.

Vegetative tests in preliminary experiments by USDA workers at Beltsville are in agreement with the nitrification results. (See Table 1)

Additional tests comparing several of these UF materials with Uramon on eight to 11 cuttings of perennial rye grass have shown a more uniform and sustained growth from the Urea-form materials, owing to their initially low but subsequently accelerated rate of nitrogen availability. Crop yields were greater later in the season when the Urea-form fertilizers were used, but the opposite was true in the early part of the season when Uramon was used.

Urea-form materials stimulated greater root and crown development on rye than they did on Bermuda grass.

A USDA cooperative program for testing these new Urea-form fertilizers in 1948 involves 35 experiments in 21 states; seven are under irrigation, eight in dry land areas, and 20 in humid regions. Results from these tests should be interesting and give us an idea of whether they have values that will warrant the expected greater costs of these newer forms.

AGRONOMIC VALUES

Now for a word about the comparative agronomic values of different sources of nitrogen that have been used locally. We feel quite safe in stating that different forms of N have equivalent sugar producing values when compared on an equivalent pound for pound nitrogen basis.

In our tests we have compared sodium nitrate, ammonium sulphate, nitrate of potash, calcium nitrate, urea, Calurea, Uramon, and ammonium nitrate. In only a rare case have the sugar yield differences been found to be significant, and where a significant difference was found in one crop, it was rarely verified in a subsequent crop. Perhaps only at Ewa where ammonium sulphate was better than nitrate of soda on the high lime, coral soils, and at Pioneer Mill Company where better juice quality was found for nitrate of soda over ammonium sulphate, have we had any consistent indications of the superiority of one source of N over another. Certainly it would be hazardous to make a generalized statement to the effect that any one form was more efficient than another. So as long as the nitrogen in different materials is present as either ammoniacal N or nitrate N, or can be converted into these forms, it should have equal agronomic value for cane crops.

However, it would not be entirely safe to continue to disregard secondary elements that are combined with nitrogen in these fertilizers, and that can exert their influence on soil conditions and crop response. It has been very difficult to place a cash value on these other elements, but they undoubtedly have one. Mainland research in long-time tests has shown good evidence of such influences. For instance, it has been pretty well established in tests in Connecticut, New Jersey, Pennsylvania, and Alabama that the long-time usage of ammonium sulphate has resulted in a reduction in soil potash. (This makes the recent findings from Mississippi interesting for it is reported that when ammonia nitrogen alone was used and soils were leached, the leaching of potash was reduced 12 per cent, whereas the loss of potash by leaching was increased by 37 per cent when ammonia was applied in ammonium sulphate.) Perhaps someday we shall learn how to properly evaluate these different effects from the secondary ions in our nitrogen fertilizers.

We have not done much along this line, but some of our recent juice analyses certainly indicate that there are effects which can be attributed to the secondary element in a nitrogen fertilizer. (See Table 2)

TABLE 2 — EFFECTS FROM SOURCE OF NITROGEN ON CRUSHER JUICE ANALYSES

Source of N	Makiki soil			Hakalau soil		
	%N	%P ₂ O ₅	%K ₂ O	%N	%P ₂ O ₅	%K ₂ O
Nitric acid.....	.075	.096	.090	.100	.024	.050
Sodium nitrate.....	.085	.080	.115	.115	.013	.070
Calcium nitrate.....	.095	.092	.095	.095	.019	.045
Mag. nitrate.....	.160	.088	.085	.140	.021	.045
Amm. hydroxide.....	.040	.128	.200	.045	.047	.095
" carbonate.....	.026	.128	.180	.026	.034	.070
" chloride.....	.090	.112	.140	—	—	—
" sulphate.....	.080	.116	.120	.105	.023	.060

New mainland developments in liquid fertilizer applications differ from our conceptions of such operations in that they are concerned with applications of liquid materials by equipment on field machines rather than in connection with irrigation water.

At present, the low price of N in ammonium nitrate suggests that we could realize immediate economies by using this material in liquid applications. A gallon of water will take up 15 pounds of ammonium nitrate at usual air temperatures here, and this makes two gallons of solution. This means that each gallon of solution will carry $2\frac{1}{2}$ pounds of N.

A 50-gallon drum of this ammonium nitrate solution on our planting machines or on our spray machines might be an easy way to put 60 pounds N per acre on two acres.

As I look ahead, I think that for the immediate future we will continue to purchase that nitrogen fertilizer which

will give us the cheapest cost per pound of nitrogen applied in the field. There will be some storage, transportation, handling, and application problems to solve before we have these total cost figures, but the high analysis materials will have many economical merits because costs of many of the items that go into the total cost of a fertilizer will be less—less for bags and for bagging, and less for freight and delivery costs, and also for profits to the middlemen, since such costs are charged at so much per ton of materials without respect to their N content.

Perhaps someday, after research has definitely established and evaluated the liabilities involved in the different nitrogen materials, and has been able to place a more definite cash value on the beneficial effects from secondary elements, we may find that the cheapest N to purchase may not be the cheapest to use in the long run, but to date, we have not established the actual cash value of such possibilities.

Filtrate Recirculation from a Rotary Vacuum Filter Measured

By H. A. Cook and M. M. Kilby

Desirability of establishing an insoluble solids balance periodically to determine the efficiency of filter operation was emphasized in a series of measurements of amount of filtrate handled from a rotary vacuum filter at Paauhau Sugar Plantation Company. Measurements were made between May 5 to 14, 1948, for eight consecutive operating days.

No facilities were available for weighing the filtrate, so volumetric measurements were based on rate of filling the settling tank. These volumes were calculated to a weight basis according to the weights found on smaller composite volumes of filtrate. Cake weights were calculated from those found on composite cake samples and from known speed of the filter. Fiber-solids determinations were made on the composite cake samples.

During the period of these measurements, conditions varied considerably, some being changed intentionally in the course of determining the effects of pH and vacuum on the filter operation and to allow for periodic tests for chemical treatment of the filtrate. Other factors such as insoluble solids in mixed juice and settlings varied greatly without any means of control, i.e., mixed juice insoluble solids ranged from 0.53 to 1.59 per cent and insoluble solids of settlings from

5.30 to 13.82 per cent. Insoluble solids in filtrate varied from 1.15 to 2.36 per cent.

Table 1 gives results of various observations made on the recirculation of filtrate during this period. The daily figures are considerably less significant than the average for the period as there is no way of estimating the tons of insoluble solids within the clarifier at any one time.

During the study it was noted that the percentage of filtrate on mixed juice averaged 16.9 with a minimum of 13.0 and maximum of 28.3. No strict correlation was found, but a tendency that the greater the amount of juice being processed the lower the percentage of filtrate was noticed. In other words, the tendency was to produce the same amount of filtrate per day regardless of the amount of juice being processed. This leveling-off of the amount of filtrate would be expected unless the filter was stopped periodically during times when the mud level was low. Slowing down the filter would cause a greater amount of wash in proportion to juice and would, therefore, tend to keep the total volume of filtrate more nearly constant. Also, if the filter speed were not reduced at lower grinding rates, the mud level in the clarifier would be lowered and the quantity of filtrate would remain constant.

TABLE 1 — FILTER RECIRCULATION DATA

Date	Filtrate		Insoluble Solids				Mud pH	Filter Min./Rev.	Cake		Solids	Solids Recirculated %
	Mixed Juice Tons/Day	Mixed Juice %	M.J. %	Filt. %	Mud %				Fiber/ Solids	Cake Tons	Filtrate Tons	
5/5/48	618	175	28.3	1.12	1.34	9.44	9.6	2:43	26.6	2.6	2.34	33.8
5/6	662	111	16.8	1.59	1.51	13.82	8.5	3:31 4:55	27.0	2.1 1.1	1.67	15.9
5/7	749	105	14.0	1.46	2.24	13.11	10.0	5:00	—	2.2	2.34	21.4
5/10	696	141	20.3	0.53	1.31	5.30	9.6	4:15	30.1	3.5 2.0	1.85	50.1
5/11	756	132	17.5	0.67	2.36	7.05	7.0	7:13	31.6	3.2	3.11	61.5
5/12	772	110	14.3	0.65	1.83	9.09	8.0	4:03 7:24	28.1 36.8	1.90 1.05	2.00	39.8
5/13	768	100	13.0	0.95	1.38	13.52	9.0	5:41	21.6	1.35	1.37	18.8
5/14	673	92	13.7	1.15	1.15	12.75	9.5	5:45	24.7	2.6	1.06	13.7
Totals	5694	996									57.20	60.28
Average	712	121	16.9	1.02	1.64	10.51	8.9	4:87	28.3	2.6	1.97	27.5

The average percentage of insoluble solids recirculated was 27.5 with a maximum of 61.5 and a minimum of 13.7 being recorded on different days. Daily averages are not considered significant because the filter occasionally operated rapidly on a day when a small amount of mixed juice was processed. It is interesting to note that when the recirculation formula

$$\% \text{ Total Recirculation} =$$

$$X \left[1 + \frac{X}{10} + \frac{(X)^2}{(10)} + \frac{(X)^3}{(10)} + \dots \frac{(X)^n}{(10)} \right]$$

is considered in which X equals the recirculation on one cycle; then the recirculation for one cycle is 22 per cent if the total recirculation is 27.5 per cent. This, therefore, means that with a total recirculation of 27.5 per cent, 78 per cent of the solids in the mud is removed with each filtration of the mud, or that, on the average, mud must go through the filter 1.28 times for complete elimination of solids in the mud.

Under the most adverse condition, there was a total solids recirculation of 61.5 per cent. On this day there was a solids recirculation of about 39.5 per cent on each cycle. It is worthy of note that an increase of 17.5 per cent of the solids recirculated on each cycle resulted in a total increase of 34 per cent on the total solids recirculated. With 39.5 per cent solids recirculated on each cycle, 60.5 per cent of the solids is removed each cycle or the mud has to pass through the filter 1.67 times on the average for complete removal of the solids. This would represent a 30.5 per cent increase in load on the filter if no change in speed of the filter were made to handle this additional load. Unfortunately this would not be the case and it would, therefore, constitute a much bigger increase in load to handle the solids removal.

There was a close correlation between

the percentage of solids in the settlings and the percentage of solids recirculated, i.e., the denser the mud the lower the percentage of solids recirculated. These figures are listed in Table 2 in the order of increasing percentage of solids in the settlings.

Of interest was the determination of the actual effective filter area. The Paauhau filter is equipped with a Goslin-Birmingham drum which, due to the wide strips used to hold the screens on the drum, has about 2½ inches that is bare between each section of the cake. If all the drum were covered there would be a 324-square-foot area. Actually, however, there are only 285 square feet of effective area.

An Oliver drum has a very narrow strip to hold the screens in place and thus the cake for practical purposes bridges this gap and the full area may be covered. In times of good cake formation on the Goslin, i.e., slow filter speed with adequate supply of fiber, the filter carried 300 square feet of cake per revolution but this unfortunately was rarely the case.

From the tabulated data we can see that for a seven-day period, omitting May 7 when the cake sample was spoiled, there were 46.25 tons solids entering in mixed juice while 60.28 tons solids were estimated as removed by filter. This is a difference of approximately 25 per cent between the tons solids entering and the tons solids recorded as being removed by the filter.

Part of this discrepancy can be accounted for by the fact that calculations were based on the filter being 300 square feet in area when, as noted above, actual measurements revealed that the cake bearing surface of the filter was about 285 square feet. On this basis the figures for solids removed by the filter can be revised to 57.25 tons for the seven days.

There is another appreciable correc-

TABLE 2 — RELATION BETWEEN SOLIDS IN SETTLINGS AND SOLIDS RECIRCULATED

Solids in Settlings %	Solids Recirculated %
5.30	50.1
7.05	61.5
9.09	39.8
9.44	33.8
12.75	13.7
13.11	21.4
13.52	18.8
13.82	15.9

tion which is for the weight of calcium phosphate precipitated and other materials carried down with it during clarification. This has been roughly estimated at 5.0 tons. Therefore, the filter removed 52.25 tons solids in seven days. Obviously it is impossible for the filter to remove more solids than there are in the juice, but

46.25 tons solids entered in mixed juice
52.25 " " removed by filter

or a discrepancy of 6.00 tons, or 6/46.25 equals 13 per cent excess removed solids. This indicates that there is 13 per cent of the filter area not effective which on the basis of the filter having 285 square feet of effective area means that there were still 37 square feet of the area not carrying any cake.

No measurements were actually made of the area that was not kept clean by the scrapers. Whereas a figure of 37 square feet per revolution seems like a very large area, it is definite that this much area and more was not cleaned a good part of the time. During a part of the subsequent phosphate juice treatment test, it was found necessary to keep a man full time at the filter to keep the drum scraped clean. By this procedure it was possible to remove a sufficiently greater quantity of solids and thus continue the phosphate treatment.

Considering these figures, it can be

seen that the filter rated at 300 square feet was discharging only 248 square feet of cake per revolution for a seven-day period or operating at 82.7 per cent of its rated capacity. As the filter capacity was the limiting factor in the grinding

rate a good part of the time, this means a 17.3 per cent reduction in the grinding rate due to inoperative filter surface, which involves operating at a grinding rate of 35 tons per hour instead of 41 tons per hour.

Weed Control on Hawaiian Sugar Cane Lands— Developments in Use of 2,4-D

By Francis E. Hance¹

In the early 1940's we found in Hawaii that 2,4-D exerted a lethal effect on certain weed growth which no contact herbicide could equal in cost or efficiency.

As research progressed the scope of usefulness expanded in utilizing this chemical for herbicidal applications. It also became apparent that volatile compounds of 2,4-D could do serious damage to vegetation other than weeds and grasses by dissemination of these compounds in air and by mechanical drift in air currents of even non-volatile solutions of the substance.

Progress was made in the development of technique in applying solutions of 2,4-D upon cultivated bare soil prior to the appearance of weed growth. This enterprise, pre-emergence weed control, not only retards the initial flush of rampant weed growth for from four weeks to three months, but it also appears to inhibit the germination of dormant weed and grass seed upon the surface and an inch or more below the ground level. Hence, sugar cane seedpieces planted three inches below the soil surface may, under favorable conditions, germinate, begin growing, and reach a height of one foot or so before having to compete with any weed or grass growth, either incipient or lush.

However, spectacular as this development has been, it is subject to severe limitations as imposed by soil characteristics, climatic conditions, and type of 2,4-D solution which is applied. For instance, in some of our soils as little as two pounds of 2,4-D applied in solution and distributed uniformly over one acre of a field planted with seedpieces at a three-inch depth will, by downward penetration in irrigation, apparently reach the seed without chemical alteration and either arrest the germination of the seedpiece or abort or even destroy the young cane shoots. In other soils, as much as 25 pounds of 2,4-D similarly employed will have no visible effect whatsoever upon the germination and growth of the new plant crop.

Another factor applicable under all climatic and soil conditions is the matter of timing of the application. If a delay has ensued in the pre-emergence application to the point where grass tufts and other hardy weed growth have appeared, then the greater part of the desired effect may be nullified and little or no retardation accomplished upon this growth (particularly grasses). Hence, a combined pre-emergence and contact application should be valuable in the general control program when delays in applying

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the treatment are unavoidable. Such has proved to be the case.

Other limitations on the efficiency of pre-emergence applications come into play where the treatment is employed in the winter months on cold, damp soils in wet country or when the cane is slow in germinating and the water-soluble 2,4-D may be dissipated or decomposed. As to the dissipation of applied water-soluble 2,4-D in wet country on soggy soil, it was believed that an oil-soluble form of the chemical in an appropriate oil vehicle would materially correct this objectionable state of affairs. To a certain extent it does and the practice is in vogue on the cold, wet uplands on the island of Hawaii. It has been found, however, that 2,4-D applied in oil solution does tend to remain on the surface for awhile, but in due course it becomes dissipated and the effect is lost. Similarly, in the effort to hold 2,4-D on the surface ground layer in pre-emergence applications on soils which do not "fix" the chemical, the downward movement of the oil solution of 2,4-D to the planted seedpieces is not always inhibited in spite of its greatly reduced solubility in the soil solution. In other respects, the finding that oil dispersions of 2,4-D are prompt in showing herbicidal effects on soils actually accrues to the advantage of the sugar planter for both air and ground equipment, in certain cases, where high concentrations of the chemical with contact amendments are to be applied at very low gallonage.

Hitchcock and Zimmerman (2) have suggested that an ideal all-purpose herbicide would contain conventional "contact" substances as usual, but that

the addition of one or more hormone constituents (2,4-D or 2,4,5-T) would markedly enhance the potency and duration of the herbicidal effect. This prediction appeared in the 1948 fall issue of the Boyce-Thompson publication. During the same year and prior to this prediction, sugar planters in Hawaii found by experience that the addition of Honocide (a 2,4-D development to* be described later) to CADE (1), a concentrated activated Diesel emulsion, actually did bolster the contact efficiency of CADE, spread the scope of its lethal action to weed growth not previously or unduly damaged, and made it possible to lengthen the intervals between contact applications.

The finding of injury to ornamental plants and trees, sensitive crops, garden vegetables, etc. by air-borne traces of the volatile ester forms of 2,4-D resulted in the establishment of an intensive research program seeking the development of equally effective liquid concentrates of 2,4-D having low vapor tension characteristics and hence little or no tendency to vaporize to the air after application in the field. This work will be described later in this paper.

In the meantime the use of ester forms of 2,4-D on Hawaiian plantations has been abruptly terminated in cultivated areas or in locations situated even remotely from sensitive vegetation. But the esters of 2,4-D should not be outlawed entirely and they most probably will not be, for they occupy a unique place in the control of woody pests second to no other presently known chemical. This subject will be covered later.

HONOCIDE

Early in 1942, in a cooperative study with F. C. Denison, Island Representative in charge of the Waipio Substation, it was found that a solution of the am-

monium salt of 2,4-D in water at a concentration of 2500 ppm would completely destroy the weed pest *Commelina nudiflora*; commonly referred to as

wandering jew on the mainland and as honohono in Hawaii. Hence, the term "Honocide." The solution was applied in but one operation as a spray to the foliage of the pest. In from 10 to 20 days the entire sprayed blanket of dense growth and root systems would be found desiccated and dead. A solution of the sodium salt of 2,4-D at a comparable concentration accomplished the same result. Later, it was found that *Ipomea*, morning glory, *Eichhornia crassipes*, water hyacinth, *Cyperus rotundus*, nut grass, and a number of others were similarly affected by foliage spraying.

A liquid concentrate just under saturation was developed in this laboratory for use in the fields where dilution water was available. It was found that at a temperature of about 75°F. a liquid concentrate containing $\frac{1}{8}$ pound of 2,4-D acid per gallon as the sodium salt would remain stable and permit a dilution of 16 times the volume of the concentrate to prepare the diluted solution described above.

FORMULA

2,4-D acid	330 lbs.
Anhydrous sodium carbonate (58% Na ₂ O)	85 lbs.
Water sufficient to make total of 1000 gals.	

DIRECTIONS Use a steel container having a capacity of about 1200 gallons. Score the inside of the tank at the 1000-gallon level. Weigh out and add the 2,4-D acid and soda ash, and then introduce water to about the 950-gallon level. Apply heat from an oil burner or electric coil previously installed below the tank. Stir contents of tank by manual or mechanical means while heat is being applied. When the temperature of the liquid reaches about 65°C. complete solution will usually have been effected. Remove source of heat, let cool, add water to the 1000-gallon mark, add about 50 cc. of a 0.5 per cent solution of fluores-

cein, and stir. This completes the preparation.

Note: The purpose of the fluorescein is to impart a characteristic yellow-green bloom to the concentrate and thus distinguish it from plain water, which it resembles.

One commonly marketed brand of 2,4-D carries a minute amount of an impurity which acts as an indicator at a pH of about 7.6 to 8.0. Using this brand of 2,4-D acid, the solution develops a brilliant cherry red. In such a case it is obviously unnecessary to add any fluorescein.

To prepare 100 cc. of Honocide in the laboratory or elsewhere, proceed as follows: Weigh out four grams of 2,4-D acid, then 1.02 grams anhydrous soda ash (58 per cent Na₂O). Place the two chemicals in a beaker, add 80 cc. water, and warm on a hot plate until acid dissolves, but not to boil. Cover and cool, then transfer solution to a graduated cylinder and dilute to 100 cc. with water. Shake and add a few drops of fluorescein solution ($\frac{1}{2}$ gram fluorescein, 25 cc. isopropyl alcohol, 1 cc. concentrated ammonia, and 74 cc. water).

Today (August 1949) Honocide is prepared on practically all sugar plantations in the Territory. The pest honohono formerly choked many fields of cane to such an extent that harvesting operations were almost impossible to carry out. One application of Honocide (1 in 16, or even 1 in 32) applied on cane and honohono destroys and desiccates the pest but does no observable damage to the cane. While honohono has all but disappeared from Hawaiian cane lands, Honocide continues in use on a rather extensive scale, but for an entirely different purpose.

Honocide is added to the herbicide CADE (1) as an amendment or hormone booster. While CADE was developed

primarily as a contact herbicide and although it is being used in this guise rather generally, it is also used to good effect when combined with Honocide as a contact-pre-emergence application. To illustrate: On May 6, 1949, on the island of Hawaii, George Groves, agriculturist at Onomea Sugar Company, requested the author to inspect a plant field of cane that was bare of all weed growth which on March 6, 1949, about 10 days after planting, had received a spray application per acre of

18 gallons Honocide
(6 pounds 2,4-D)
12.5 gallons CADE
69.5 gallons water

Total 100 gallons

Light weed growth had appeared at the time the field was sprayed. It was definitely free of weed growth at the day of inspection, two months later.

A laboratory study of the miscibility of Honocide with several commonly used contact herbicides indicated that with the stabilizing influence of a number of coupling agents, alkyl aryl sulphonate, isopropyl alcohol, etc., Honocide may be incorporated with chlorates, arsenites, HSPA Activator (U. S. Patent No. 2,370,349), thiocyanates, and so on.

CONCENTRATE NO. 2A

Laboratory studies which followed indicated that several amine forms of 2,4-D could be employed as fairly satisfactory substitutes for the esters. These amines could be formulated at reasonably high concentrations, producing water-soluble stock solutions having negligible vapor tension and hence not given to dissemination in air currents by vapor movement.

The first amine-type of 2,4-D concentrate was developed early in 1948. The formulation was released for plantation preparation and field use on April 27,

Honocide is being used on an increasing scale for field application in pre-emergence by plane and helicopter. It is usually stepped up in concentration of 2,4-D for this work by the addition of special amine concentrates of 2,4-D which will be described later. This practice in air application of pre-emergence would most likely give way to the exclusive use of the more concentrated amine forms of the hormone were it not for the claim by a few workers that with Honocide in the formula the aviators can more readily check their pattern of application in progressive field sweeps by the visible "frosting" film which may be observed along the sweep just completed. This film consists, of course, of the sodium salt of 2,4-D, the water solvent having evaporated.

The low concentration of 2,4-D in Honocide, with its accompanying bulk, introduced logistic problems in its large-scale field usage, particularly for low-gallonnage applications. Up until the time that the vapor drift of the esters of 2,4-D played havoc with vegetation located even miles away from the site of application, very effective emulsions of the isopropyl ester of 2,4-D came into rather widespread use. However, this practice had to be abandoned.

1948. The product is soluble in water in any proportion and the solution so produced is clear and stable. One gallon of this concentrate weighs 10.85 pounds and carries the equivalent of five pounds of 2,4-D acid. It is non-corrosive to metals, rubber, or spraying equipment. It is hygroscopic and hence exhibits a low vapor tension. It contains a glycol conditioner which is designed to protect the concentrate from deterioration in storage. This product is 15 times more concentrated in 2,4-D than is Honocide.

FORMULA

2,4-D acid	200 lbs.
Triethanolamine... (15 gallons)	140 lbs.
Diethylene glycol mono ethyl ether ²	½ gal.
Water	10½ gals.

Makes a total of 40 gals.

DIRECTIONS 1. Select a clean, 54-gallon steel drum, one head removed.

2. Elevate the drum six or eight inches above the ground in order to apply a source of mild heat (open fire under drum is all right). Scribe the inside of the drum at the 40-gallon level.

3. Add the triethanolamine and the Carbitol to the empty drum. In a clean container, measure the volume of water indicated in the formula. Use this water to rinse the amine and Carbitol measuring cans, adding the rinsings to the drum.

4. Stir contents of drum with a heavy pole; the amine is heavy and viscous.

5. With the application of mild heat, add the 2,4-D acid in successive portions of about 10 pounds, and stir gently with each addition. Do not allow the temperature of the mix to become higher than 65°C. In about one hour the reaction will have subsided, the 2,4-D acid having been converted to a soluble amine.

6. Remove source of heat and cover the container.

7. When cool, add more water, if

necessary, to bring the volume of the concentrate to 40 gallons. This completes the operation.

To prepare 100 cc. of Concentrate 2A in the laboratory or elsewhere, proceed as follows: To a 250-cc. wide mouth Erlenmeyer flask, add

2,4-D acid.....	60 grams
Triethanolamine.....	42 grams
Carbitol.....	1.5 cc.
Water.....	26.0 cc.

This makes a total volume of 100 cc.

Stir the mixture and warm to 60°C. until reaction has been completed and a clear solution is obtained.

Concentrate No. 2A was well received on the plantations and large volumes of the product have been and still are being manufactured and utilized.

In spite of this the product has its limitations and is objectionable in several respects. It is heavy bodied and viscous, and requires heating in its formulation. As a blending source of 2,4-D it is not entirely satisfactory because stabilizing and coupling agents are required to hold its 2,4-D in solution with contact herbicides containing chlorates and the water-soluble HSPA Activator.

Nevertheless, Concentrate 2A is outstanding in its chemical stability, freedom from vapor drift, excellent keeping qualities even when exposed in storage, and freedom from objectionable odor.

CONCENTRATE NO. 2D

To meet the demand for a 2,4-D amine concentrate which could be blended with solutions of the water-soluble HSPA Activator and with CADE emulsions without incurring chemical antagonism, a new formulation was developed using triethylamine as the basic amine raw material.

On July 16, 1948, the formulation, described as Concentrate 2D, was released

for plantation use, and its advantages and disadvantages pointed out.

ADVANTAGES 1. It is very thin and light bodied, producing a concentrate of 2,4-D which is considerably less viscous than Concentrate 2A. It carries the equivalent of five pounds of 2,4-D acid in one gallon.

2. Owing to the vigorous reaction

² An excellent brand of this chemical is marketed under the trade name of Carbitol.

which takes place when this compounded triethylamine is brought in contact with 2,4-D acid, sufficient heat is produced to effect complete solution of the 2,4-D without the necessity of applying external heat.

3. It is miscible with the HSPA Activator and with CADE.

DISADVANTAGES 1. It has a disagreeable odor which appears to nauseate some persons.

2. It has a very low flash point and may be ignited quite readily by the flame of a match.

3. Unneutralized triethylamine will burn cane foliage. (Figure 1).

Concentrate 2D may be prepared from a blended compound of 88 per cent triethylamine with 12 per cent of other amine derivatives and water which is marketed as Sharsol 193 by Sharples Chemicals Inc. of Philadelphia, Pennsylvania.

FORMULATION

2,4-D acid.....	200	lbs.
Triethylamine blend (Sharsol 193).....	110.4	lbs. (17.8 gals.)
Water.....	74.4	lbs. (8.9 gals.)
Makes a total of	40	gallons

DIRECTIONS Follow the procedure described in preparing Concentrate 2A, omitting the application of external heat. Keep the mixing container covered as much as possible during the preparation of the concentrate to protect the operator from the not too pleasant odor of the mixture. Heat of reaction effects solution. Avoid sparks or flames in the vicinity of the mixing plant. After completion of the formulation, transfer the concentrate to clean steel containers (drums are good). Make certain to close tightly all plug outlets to circumvent evaporation and consequent deterioration.

Figure 1.



To prepare 100 cc. of Concentrate 2D in the laboratory or elsewhere, proceed as follows:

To a 250-cc. Erlenmeyer flask add 60 grams of 2,4-D acid, followed by 22 grams of water. Now add (preferably on the balance) 33 grams of Sharsol 193. Stopper the flask loosely and rotate gently. The mixture becomes warm but in this small batch the heat of reaction is rapidly dissipated. Now stopper the flask more tightly and, with occasional shaking, set it in a warm place (50°C.) for a short time or until the solution becomes clear.

Concentrate 2D is an excellent blending amine. It may be incorporated with CADE, HSPA Activator, sodium chlor-

ate, and other contact herbicides. For pre-emergence-contact applications at very low gallonage (2½ gallons per acre), the following formulation is in use on a Hawaiian plantation:

Water-soluble HSPA	
Activator.....	1.8 lbs.
25% solution alkyl aryl	
sulphonate (Wetting	
Agent 2-7-R).....	½ pint
Water sufficient to make a	
total volume of.....	2 gallons
Dissolve and add Concen-	
trate 2D.....	½ gallon
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Makes 2 ½ gallons	

The formulation contains 1.8 pounds of activator, 2½ pounds 2,4-D acid equivalent, and ample wetting agent in the 2½ gallons of solution.

STOCK SOLUTION OF ACTIVATOR AND 2,4-D

The triethylamine blend (Sharsol 193) may be used with 2,4-D acid and the HSPA Activator directly in preparing a stock solution for adding to CADE for effective contact field application. It may be prepared as follows:

Standard 2-7-R solution	
(25% alkyl aryl sulpho-	
nate).....	5 gals.
Sharsol 193 (triethylamine	
88%).....	7 gals.
Carbitol.....	5 pints
2,4-D acid.....	50 lbs.
Water.....	30½ gals.
Water-soluble HSPA Acti-	
vator.....	60 lbs.
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Makes approx. 50 gallons.	

DIRECTIONS Add the 2-7-R solution, triethylamine, and Carbitol to a clean

steel drum which has been calibrated and mounted above a mild source of heat. Now add the 2,4-D acid and stir until it is completely dissolved. Next add the water, then the activator, apply gentle heat, and stir. In a short time a clear solution will be formed. Protect this product from exposure to air.

For field use dilute 6¼ gallons of the above stock solution with 81 gallons of water. Add 12½ gallons of CADE and stir. This produces 100 gallons of improved contact herbicide emulsion sufficient for one acre and containing 6¼ pounds 2,4-D as amine and the regulation quota of activator, wetting agent, and homogenized Diesel oil.

PRE-EMERGENCE-CONTACT SPRAYS

A decided swing to a combined contact and pre-emergence application is taking place in Hawaii. The reason for this movement is a very practical one. A cultivated field, just prepared for a crop of cane, may have to remain untreated for a week or 10 days to accommodate the plantation schedule. In such

cases weed and grass growth may get a start before a pre-emergence treatment may be applied. Then grass tufts and some resistant weeds which have appeared may not succumb to the pre-emergence application, whereas surface weed and grass seeds will be destroyed. Hence, the addition of a suitable potent

contact herbicide to the pre-emergence chemicals accomplishes the double purpose.

However, there are times when pre-emergence alone is all that is required. This broadens the scope of 2,4-D-type chemicals which may be used. Since amines are generally satisfactory and since the unit costs of basic amines vary so widely, the agriculturist may realize a substantial saving by using one or more of the cheaper gaseous amines in water solution as solubilizers of 2,4-D. Advantage may also be taken of those basic

amines which produce concentrates of 2,4-D that are not miscible with the general run of contact herbicide chemicals. Hence, formulations of various concentrations of 2,4-D may be prepared from monoethylamine, dimethylamine, and a mixture of 80 per cent diethylamine with 20 per cent triethylamine. As a rule, concentrates prepared from these three basic amines may be formulated without the necessity of applying external heat in the processing. Laboratory formulations and comments concerning each type of concentrate follow.

CONCENTRATE 2E

This is an inexpensive and stable concentrate carrying five pounds 2,4-D (calculated to acid) per gallon. It is prepared from a 25 per cent solution of the gas dimethylamine. However, its low cost is offset by its atrocious odor. No external heat is required in its preparation, and it is soluble in water in any proportion. It may be prepared in the laboratory easily and quickly, as follows:

2,4-D acid	60 grams
Water.....	6 cc.
25% solution dimethylamine.	57 cc.
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Makes 100 cc.	

DIRECTIONS Add the water and dimethylamine solution to the acid. Stopper loosely and swirl container. In a short time a clear solution is formed.

Caution: Dimethylamine is combustible and explosive; avoid sparks and flames.

CONCENTRATE 2F

Another low-cost concentrate carrying five pounds 2,4-D (acid) per gallon which is soluble in water in any proportion. Its odor is quite mild and scarcely offensive to anyone. No external heat is required in its preparation, and it may be manufactured from a blend of basic amines consisting of 80 per cent diethylamine and 20 per cent triethylamine. This amine product is marketed as Sharsol 241. The formula follows:

2,4-D acid	60 grams
Water.....	34 grams
Sharsol 241.....	22 grams
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116 grams = 100 cc.	

DIRECTIONS Add the water to the acid, then the Sharsol 241. Loosely stopper container and swirl. When heat of reaction reaches its peak, close stopper tightly and shake. A clear solution is formed in less than 15 minutes.

CONCENTRATE 2G

This is another amine formulation of 2,4-D and the least costly of any of the gaseous amine concentrates. It is stable

only at a concentration of one pound 2,4-D (as acid) per gallon of concentrate. It is soluble in water in any proportion

and is actually pleasant in odor. No external heat is required in its formulation. It may be prepared in the laboratory or elsewhere easily and quickly from a 70 per cent solution of monoethylamine in water. The formula:

2,4-D acid	12 grams
Water.....	90 cc.
70% solution in water of monoethylamine.....	5 cc.
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Makes	100 cc.

VOLATILE BASIC AMINES

Over a period of about one year in numerous glass house and field experiments we found that many of the volatile basic amines (dimethylamine, di- and triethylamine, etc.) were toxic to sensitive vegetation even without having been processed with 2,4-D. In the laboratory it was determined that the liquid reaction product resulting from a carefully balanced equimolecular combination of 2,4-D acid and an amine blend, say Sharsol 241, actually constituted an ideal solvent for an additional 40 per cent or more of the 2,4-D acid originally processed. In other words, we found that about 60 per cent of the theoretical amount of basic amine required to react with any given amount of 2,4-D acid would produce a new type of concentrate having the following outstanding characteristics:

- Unusually stable.
- No solidification or crystallization in storage, even when exposed to the air.
- Carries up to 7½ pounds 2,4-D (calculated to acid) per gallon of concentrate and such a concentrate will not crystallize on seeding nor solidify in open storage.
- Cost of processing greatly reduced.
- Soluble in an equal volume of water.
- For bringing about solution in large volumes of water, say one gallon of a seven-pound 2,4-D concentrate in 200

DIRECTIONS Add about ¼ of the water to the 2,4-D acid and stir the mixture into a thin slurry. Now add the 70 per cent solution of monoethylamine and stir until the acid is almost completely dissolved. Then add the balance of the water and stir. When solution is clear, add it to a tight-fitting container. One gallon of this concentrate carries exactly one pound of 2,4-D (calculated to acid).

gallons of water, a small amount of inexpensive alkali (soda ash) may be used.

● An actual deficiency of free basic amine exists in concentrates of this character. Hence, no secondary vegetative toxicity from this source is possible. (This fact has been established in pot tests under bell jars.)

This new type of concentrate is slightly disadvantageous in that it requires a certain amount of attention prior to its formulation in the mixing plants, but its advantages are:

- Absolute stability as a stock supply of liquid 2,4-D at high concentration (remains stable at 3°C.).
- It will not crystallize nor solidify even when seeded and exposed to the air.
- Markedly cheaper in the processing of 2,4-D.

The formula for preparing a typical concentrate of this type follows:

CONCENTRATE 2H (Special)

2,4-D acid.....	84 grams
Water.....	20 grams
Sharsol 241.....	20 grams
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	124 grams

This makes a total volume of 100 cc. and contains seven pounds 2,4-D (calculated to acid) per gallon.

For dilution with water, dissolve one pound of anhydrous soda ash (58 per cent Na₂O) in the diluting water for

every gallon of Concentrate 2H (Special) to be diluted.

Note: An improved development of the same type will be de-

scribed later (Concentrate 7A) which does not require alkali for its dilution with water.

PRE-EMERGENCE-CONTACT BY AIRCRAFT

Due to the limited pay load a helicopter can carry and the speed of spray application it can discharge, a highly concentrated oil solution of herbicide appears to find favor with the aviators. About seven gallons of liquid are applied per acre. Contact as well as pre-emergence characteristics are sought. A formulation developed for the purpose in this laboratory follows. It carries 2,4-D

and oil-soluble HSPA Activator (pentachlorophenol).

Mix in the cold:

2,4-D acid	3 lbs.
Isopropyl alcohol 99%.....	$\frac{3}{4}$ gal.
Oil-soluble HSPA Activator..	9 lbs.
Light aromatic by-product petroleum oil ³	$5\frac{1}{3}$ gal.

Makes solution of 7 gallons

A LIQUID CONCENTRATE OF 2,4-D SOLUBLE IN OIL OR WATER

As a result of the experience gained in the research on the various amines of 2,4-D and to meet an insistent demand by plantation men for a highly concentrated and foolproof liquid form of 2,4-D which could be processed as a blending amine and also diluted with oil or water, an attempt was made to develop a concentrate meeting these requirements.

Preliminary study was carried out in Honolulu and brought to a conclusion on the mainland with the cooperation of the chemistry staffs of an eastern university and a manufacturer of chemicals. Upon the return to Honolulu a formulation was developed (Concentrate 7A) which embraces the following characteristics:

- It carries seven pounds of 2,4-D (calculated to acid) per gallon.
- It will not crystallize by seeding.
- It is free from any uncombined basic amine.
- It is soluble in water in many proportions.
- It is soluble in aromatic oils in any proportion by coupling the mixture with

a small amount of the inexpensive, tax-free isopropyl alcohol.

- Its diluted solution is miscible with major contact herbicides in a number of simple manipulations.
- It is an extremely stable liquid form of triethylamine of 2,4-D and may be prepared without applying external heat.
- It does not break down nor solidify in storage by exposure nor by careless handling.
- It is suitable for processing with CADE or similar herbicide emulsions.

DIRECTIONS FOR 40 GALLONS Scribe a 50-gallon steel drum (head removed) at the 40-gallon level. Prepare a fairly tight-fitting cover. Lag the outside and under side of the drum with asbestos or other insulating material. This lagging is for the purpose of conserving the heat generated by the mixing operation so as to avoid applying external heat. Place the drum in a shed or to the lee of a building away from strong winds to reduce loss of the triethylamine used in the process. The formula:

³ An excellent oil for this formula is marketed as 4060-0 oil by Union Oil Company of California.

2,4-D acid 99% purity.....	280	lbs.
Water.....	5 $\frac{1}{3}$	lbs.
Triethylamine 88% ⁴	130	lbs.
Total (volume of 40 gallons)	415	pounds

Add the 2,4-D acid to the prepared drum and then the water, followed immediately by the triethylamine. The triethylamine should be added in a slow, steady stream, stirring constantly, and regulating the rate of addition by the amount of heat which is generated; this heat will be needed to complete the process. After stirring a few minutes, cover the drum and then stir occasionally until a clear solution remains. Allow the reaction mixture to stand overnight tightly covered. Then transfer to stock container.

Note: The chemical research preceding the development of this formulation will not be discussed in this paper because it is somewhat involved and quite technical. The amounts and ratio of the three constituents used are important and govern the stability, and physical and chemical properties of the concentrate.

The investigator should, by all means, prepare a 100-cc. specimen of Concentrate 7A before attempting to manufacture a large batch. Directions follow for this purpose. Suggestions are also included for testing the concentrate and for processing it in various combinations for potential field use.

TO PREPARE 100 CC.

2,4-D acid.....	83.8	grams
Water.....	1.6	grams
Triethylamine 88%.....	39.0	grams
	124.4	grams = 100 cc.

Secure a wide-mouth eight-ounce bottle and tightly fitting cork, a suitable powder funnel, and an improvised warmer to hold the temperature of the reaction mixture at about 50°C. (The warmer may consist of a metal plate attached to a ring stand with a 100-watt electric bulb mounted in contact with and directly below the plate. The purpose of the warmer is to compensate for the heat lost by radiation in preparing such a small quantity of the concentrate.) Place the powder funnel in the dry bottle and transfer to the balance pan. Obtain weight. Set the balance first for the 2,4-D acid and weigh it in. Next set the balance for the water and introduce directly on the 2,4-D acid. Finally add the correct weights for the basic amine (88 per cent triethylamine) and introduce the amine upon the acid and water. Now stopper the bottle very tightly and, holding the cork in place, shake the mixture vigorously. It will become warm. Place the mixture on the improvised warmer and allow it to remain there for five or six hours with occasional shaking. (It is not necessary nor desirable to vent the reaction mixture by easing off on the cork.) A straw-colored, clear syrupy solution will be formed if pure chemicals are employed. The following day the concentrate will be ready for use.

The following materials will be needed for processing the concentrate:

- Good quality tap water.
- A light bodied aromatic by-product petroleum oil. Such an oil was previously described as 4060-0 oil.
- Isopropyl alcohol (99 per cent)—not rubbing alcohol.
- A 25 per cent water solution of an alkyl aryl sulphonate (wetting agent previously described). There are many such preparations on the market. In

⁴ Marketed as Sharsol 193 by Sharples Chemicals Inc., Philadelphia, Pennsylvania.

Hawaii we use a compound prepared for us by Standard Oil Company of California. We term it "2-7-R." It is an unctuous paste soluble in water. Two pounds of the paste are brought in solution with sufficient water to make one gallon.

● CADE.⁵

● Stock Solution of Activator—SSA (1).

SOLUBILITY IN WATER The concentrate (seven pounds 2,4-D, active but not volatile) may be diluted with water as follows: Adding from 1 to 14 gallons of water to one gallon of the concentrate forms clear, stable solutions. In adding from 14 gallons to 40 gallons of water to one gallon of the concentrate, about a quart of 2-7-R solution must be included in this range of dilution to hold the 2,4-D in solution. Adding from 40 gallons to 200 gallons or more of water to one gallon of the concentrate will produce a clear solution without the necessity of using the 2-7-R coupler. From the one to 14-gallon range, the concentrate dissolves the water. The reverse of this is true in the higher dilutions.

SOLUBILITY IN AROMATIC OILS One gallon of the concentrate will dissolve in any volume of the oil desired, provided the concentrate is first diluted with a small amount of 99 per cent isopropyl alcohol. The purpose of the alcohol is to stabilize the solution and compensate for the water necessarily used in preparing the concentrate. A pure aromatic hydrocarbon will dissolve Concentrate 7A without the necessity of including any alcohol whatever.

REINFORCING CADE

When the herbicide is to be applied immediately after diluting the CADE and adding the concentrate (CADE 1 in 8 plus 3½ pounds 2,4-D per 100 gallons), proceed as follows: To a clean 54-gallon steel drum add 40¾ gallons water and three gallons of SSA. Stir and add six gallons CADE. With constant stirring, add one quart of Concentrate 7A. Mix and apply immediately. The diluted emulsion so prepared will remain stable several hours. However, when the diluted emulsion is to be kept on hand for several days, a smooth, stable dispersion of the components may be obtained by compounding the formula in the order given below, stirring after each addition:

Water.....	39¼ gals.
2-7-R solution.....	1½ gals.
SSA.....	3 gals.
Concentrate 7A.....	¼ gal.
CADE.....	6 gals.

Total 50 gallons.

This formulation or its equivalent, using other concentrates of 2,4-D, has been found very effective as a pre-emergence-contact application. It is used in large volume by plantation men.

Concentrate 7A may also be formulated with diluted arsenites; it may be used in the preparation of low-gallage applications—pre-emergence or contact—for helicopter, plane, or land-operated equipment. Concentrate 7A is quite versatile. It appears to constitute a liquid form of 2,4-D which will keep indefinitely and furnish a stock source of concentrate for employment in most any formulation, water, oil or emulsion, which the agriculturist may desire to use.

AN EFFECTIVE TREE KILLER

The control of woody pests on ranch and pasture lands has always been a

problem. Research in this laboratory, and independently by James Cowan of

⁵ CADE is an emulsion of Diesel oil 67 per cent, aqueous solution 33 per cent. SSA is a solution of water-soluble HSPA Activator 120 pounds, 2-7-R solution 10 gallons, and sufficient water to make 100 gallons.

Pacific Chemical & Fertilizer Company, has shown that the isopropyl ester of 2,4-D can be used to good effect in destroying such woody pests as *Lantana Camara*, lantana, *Psidium Guajava*, guava, *Schinus terebinthifolius*, Christ-mas berry, *Eugenia jambolana*, Java plum, etc. A Diesel oil solution of the ester is applied directly to the bark of the basal portion of the tree or to the lower branches of scrub growth. We have found it advantageous to incorporate an oil-soluble emulsifying agent with the compound to insure its absorption by the sap of the tree and its subsequent trans-location to the root system. The com-pound may be prepared by simply mixing the following liquids:

TREE KILLER NO. 1

HSPA Concentrate No. 1 ⁶	1 gal.
Diesel oil.....	9 gals.

Makes 10 gallons.

The tree killer may be applied by paint brush or by a fine stream (not a spray) from a suitable portable device. One or two fluid ounces applied at random di-rectly on the bark of a five- or six-foot tree anywhere below the foliage is suf-ficient to destroy the tree in all cases so far studied. It is not necessary to pre-

pare the tree in any manner before the application. One treatment is sufficient, as a rule, but the ultimate destruction of the pest may not occur until from three months to a year has elapsed, and in some cases an additional application may have to be made. The investigator should bear in mind this delayed effect of the treatment.

While it is entirely safe to apply the tree killer in areas far removed from cul-tivated crops or other sensitive vegeta-tion, it is dangerous in the extreme to spread the compound in large amounts on tree or brush growth in agricultural or urban localities. In an effort to overcome this objection to the tree killer and to substitute a potent, non-volatile amine of 2,4-D for the ester, the following formulation has been compounded:

TREE KILLER NO. 2

HSPA Concentrate 7A.....	10 gals.
Isopropyl alcohol 99%.....	2 gals.
G-1096 (described above)....	2 gals.
4060-0 oil (described above)..	86 gals.

Makes 100 gallons

This formulation is now being com-pared with Tree Killer No. 1 on a large upland woody range on the island of Oahu.

LITERATURE CITED

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- 2 HITCHCOCK, A. E., and ZIMMERMAN, P. W. Activation of 2,4-D by Various Adjuvants. Boyce-Thompson Inst. Contrib. 15:173-193. 1948.

⁶ A liquid concentrate consisting of 85 per cent by weight of isopropyl ester of 2,4-D and 15 per cent by weight of an oleic acid derivative of poly oxy ethylene hexa hydric alcohol marketed as G-1096 (Atlas Powder Company).

